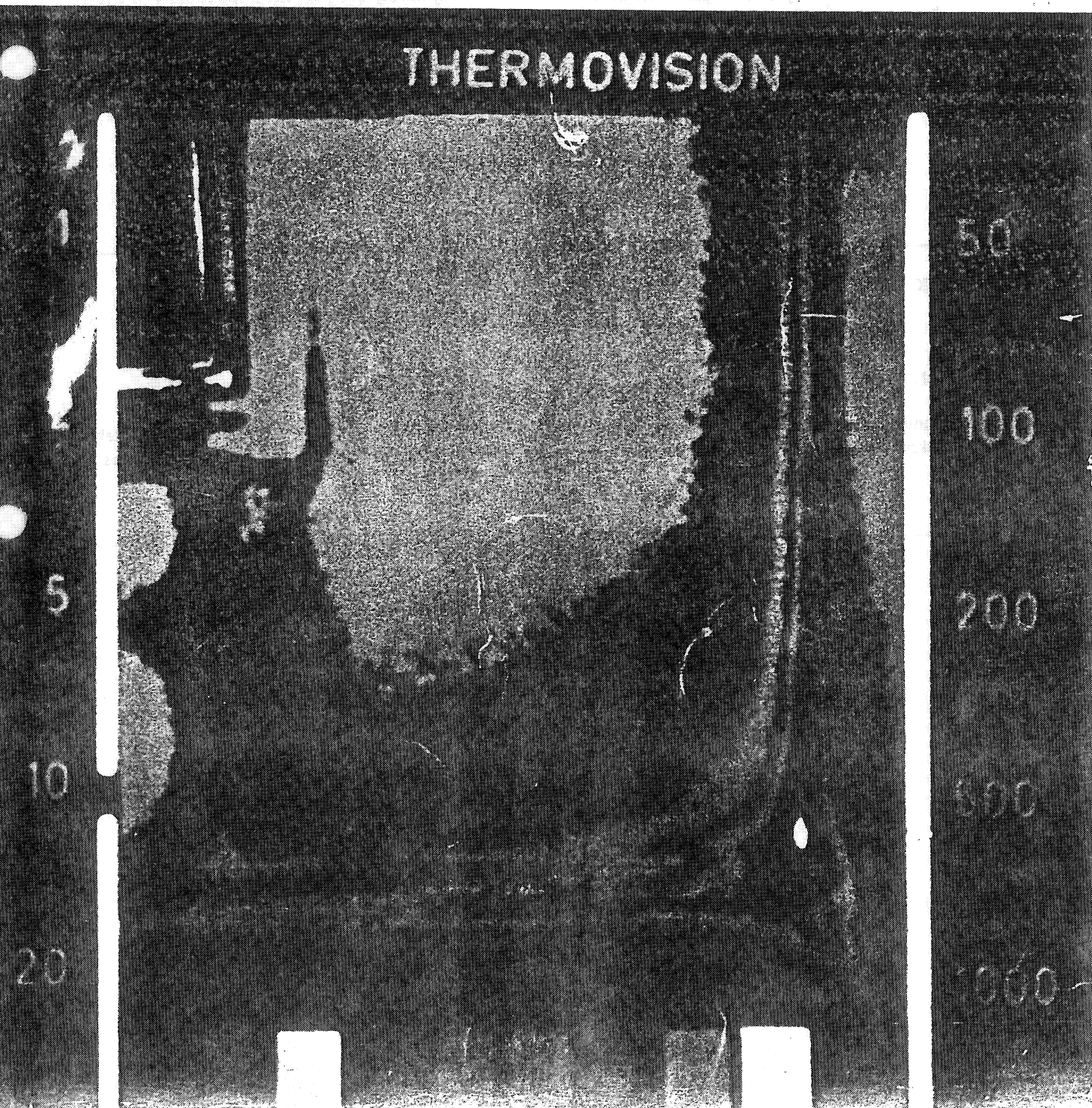


**mografering
bygggnader**

**ermography
uildings**

Byggforskningen



Denna skrift hänför sig till anslag C 498 från Statens råd för byggnadsforskning. Försäljningsintäkterna tillfaller fonden för byggnadsforskning.

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31 – 42 Sandwichvägg		31 – 42 Sandwich wall unit	
43 – 56 Lättbetongvägg		43 – 56 Light concrete wall	

E	energiflöde per ytenhet energy flux per unit area	W/m^2
ΔI	skillnad i isothermenheter mellan två isothermmarkeringar på gråtonskalan difference in isotherm units between two isotherm markings on the grey scale	
IR	infraröd infrared	
m	värmemotstånd hos väggkonstruktionen thermal resistance of the wall structure	$m^2, ^\circ C/W$
m_i	värmeövergångsmotstånd på konstruktionens insida surface resistance on the inside of the structure	$m^2, ^\circ C/W$
m_u	värmeövergångsmotstånd på konstruktionens utsida surface resistance on the outside of the structure	$m^2, ^\circ C/W$
p_i	lufttryck på insidan av väggen air pressure on the inside of the wall	N/m^2
p_u	lufttryck på utsidan av väggen air pressure on the outside of the wall	N/m^2
$\Delta p = p_i - p_u$	(skillnaden i lufttryck, inne – ute) (difference in air pressure, indoors – outdoors)	N/m^2
q	värmeflöde per ytenhet heat flow per unit area	W/m^2
T	absolut temperatur absolute temperature	K
t	temperatur temperature	$^\circ C$
t_i	innetemperatur indoor temperature	$^\circ C$
t_u	utetemperatur outdoor temperature	$^\circ C$
Δt	temperaturskillnad motsvarande isothermskillnaden i termogrammen temperature difference corresponding to the isotherm difference on the thermogram	$^\circ C$
α	värmeövergångskoefficient surface coefficient of heat transfer	$W/m^2, ^\circ C$
$\alpha_i = 1/m_i$	värmeövergångskoefficient på konstruktionens insida surface coefficient of heat transfer on the inside of the structure	$W/m^2, ^\circ C$
$\alpha_u = 1/m_u$	värmeövergångskoefficient på konstruktionens utsida surface coefficient of heat transfer on the outside of the structure	$W/m^2, ^\circ C$
ϵ	emissionstal emissivity	
λ	våglängd (strålning) wavelength (radiation)	μm
Λ	värmegenomföringskoefficient thermal conductance	$W/m^2, ^\circ C$
ρ	reflektionstal reflective index	

1 Problem, målsättning

Inventeringar av byggnadsskador under senare år har visat att grova byggfel numera är tämligen vanliga hos nybyggda bostadshus, Carlsson & Nylander (1970) och Elmroth (1970). Bland de vanligaste fe-len som åsamkar husägaren åtskilligt obehag kan nämnas brister i värmeisolering och otäthet i fogar. Dessa fel förorsakar ökad värmeförbrukning, sanitär olägenhet för de boende genom kalluftströmning och strålning från kalla ytor samt ibland kondensbildning och nedsmutsning av väggytorna. Fel av nämnda typer är svåra att upptäcka vid okulärbesiktning av nybyggnader och uppdagas vanligen först när huset använts viss tid, ofta tyvärr efter det att garantibesiktning redan blivit utförd.

Det vore därför av stort intresse för husköparen om byggfel av typ värmeisolerfel och luftläckage kunde upptäckas och repareras före slutbesiktning.

Under senare år har lokalisering av isoler- och läckagefel försöksvis utförts i Sverige genom uppmätning av temperaturfördelningen hos väggytor. Ojämheter i värmeläckage hos ytterväggar resulterar nämligen i en temperaturvariation utefter väggytan. En kvalitativ bild av värmefflödesfördelningen i en byggnadskonstruktion kan således fås genom bestämning av temperaturfördelningen längs med konstruktionens yta. Även otätheter som tillåter en luftströmning genom väggen påverkar väggens yta genom en lokal sänkning eller höjning av temperaturen hos väggpartiet i närheten av läckagestället. Om ytemperaturmätning kunde utföras på ett ändamålsenligt sätt, skulle den skisserade metoden bli mycket användbar för lokalisering av isolerfel hos byggnader. Termografering med värmekamera (infrarödkamera) har visat sig motsvara kraven på en sådan mätmetod. En värmekamera omvandlar i princip värmestrålningen (infrarödstrålningen) som utsänds från mätobjektet till elektriska signaler som överförs till en gråtonsbild på en oscilloskopskärm.

Termografering har följande fördelar framför andra temperaturmätmetoder:

1. Mätning sker momentant över stora ytor.
2. Mätning sker utan störande kontakt mellan föremål och mätinstrument.
3. Mätning kan utföras på stora avstånd från mätobjektet varigenom svåråtkomliga mätställen kan nås.
4. Snabb undersökning av stora måtytor kan utföras genom panorering från en mätposition.

Vid tillämpning av termografering för undersökning av byggnader uppstår problem av två slag:

1. Hur kan tillförlitliga slutsatser om en väggs inre egenskaper (isoleregenskaper) fås ur en ytempe-

1 Problems and objectives

Analysis of damage to buildings in recent years has shown that serious constructional defects are fairly common in newly constructed residential buildings, Carlsson & Nylander (1970) and Elmroth (1970). Defects in heat insulation and heat leakage in joints deserve special mention among the most common defects which cause the owner of the property a considerable amount of inconvenience. These defects cause an increase in the consumption of heat and also give rise to sanitary inconvenience for those living in the premises owing to cold draughts and radiation from cold surfaces and possibly also condensation on the walls which makes these dirty. Defects of the above type are very difficult to detect during a visual inspection of new buildings and are usually discovered when the building has already been in use for some time, unfortunately often when the final inspection for the building guarantee has already been carried out.

It is therefore of great interest for purchasers of property that it should be possible for building defects of the heat insulation defect and heat leakage type to be discovered and put right prior to final inspection.

Experiments have been carried out in the past few years in Sweden on the location of defects in insulation and points of heat leakage by measurement of the temperature distribution over wall surfaces. Variations in leakage of heat through external walls result in a variation of temperature along the surface of the wall, and it is therefore possible to obtain a qualitative picture of the heat flow distribution in a building structure by determination of the temperature distribution along the surface of the structure. Points of leakage which permit flow of air through the wall also exert an influence on the surface of the wall by virtue of the fact that there is a local drop or rise in temperature over the part of the wall in the vicinity of the point of leakage. If it were possible to measure the surface temperature in the appropriate way, the method outlined above would be very suitable for the location of insulation defects in buildings. Thermography with an infrared camera has been found to satisfy the requirements applicable to such a method of measurement. In principle, an infrared camera transforms the heat radiation (infrared radiation) emitted by the object of measurement into electrical signals which are converted into a monochrome image on the screen of an oscilloscope.

Compared with other methods of temperature measurement, thermography has the following advantages:

1. Measurement is carried out instantaneously over large surfaces.

raturfördelning hos väggens ytteryta? Yttemperaturen hos en yttervägg påverkas ju även av andra faktorer än väggens värmemotstånd.

2. Hur inverkar ytans egenskaper, såsom emissions-tal och eventuell genomsläpplighet för värmestrålning på korrekt återgivning av ytans verkliga temperatur?

Föreliggande undersökning avsåg att närmare klarlägga förutsättningarna för termografering av byggnader samt utarbeta regler för termografering och tolkning av termogram. Arbetet har utmynnat i dels förslag till anvisningar för fältmätningar dels förslag till tolkningsregler för termogrammen. För anvisningarna och tolkningsreglerna redogörs i det följande.

2. Measurement is carried out without interference due to contact between the object and the measuring instrument.
3. Measurement can be carried out at large distances from the object of measurement, and measurement sites which are difficult to approach can therefore be dealt with in this way.
4. Quick examination of large measurement surfaces is possible by panning the instrument from *one* measurement point.

Two types of problems arise in applying thermography for the examination of buildings:

1. How can reliable conclusions as to the internal properties (insulation properties) of a wall be drawn from a measurement of the temperature distribution along the external surface of the wall? The surface temperature of an external wall is affected by factors other than the thermal transmittance of the wall.
2. In what way do the properties of the surface, such as its emissivity and possibly permeability to infrared radiation, affect correct reproduction of the actual temperature of the surface?

The aims of this investigation were to examine in greater detail the conditions applicable to thermography of buildings and to draw up rules for thermography and the interpretation of thermograms. The results of this work have been draft instructions for field measurements and draft interpretation rules for thermograms. The instructions and rules of interpretation will be described in the following.

2 IR-kamerans funktionssätt¹

2 The method of operation of the IR-camera¹

2.1 Fysikalisk bakgrund för temperaturmätning med infrarödteknik

Temperaturmätning med infrarödteknik bygger på förhållandet att all materia p.g.a sitt värmeinnehåll ständigt utsänder energi i form av elektromagnetisk strålning. Den från ett föremål utstrålade energin, energiflödet, är en funktion av ytans temperatur. Energiflödet beror dessutom av ytans emissionstal, ϵ och strålningens våglängdsområde, $\Delta\lambda$, se Grigull (1961). Förhållandet åskådliggörs i FIG. 1 och 2. I FIG. 1 presenteras strålningsintensiteten från en

¹IR är förkortning av infraröd.

IR is an abbreviation of infrared.

2.1 The physical background to temperature measurement using infrared techniques

Temperature measurement using infrared techniques is based on the fact that all matter, owing to its heat content, continuously emits energy in the form of electromagnetic radiation. The energy radiating from an object, the energy flux, is a function of the temperature of the surface of this object. The energy flux is also dependent on the emissivity (ϵ) of the surface and the wavelength range ($\Delta\lambda$) of the radiation, Grigull (1961). This state of affairs is illustrated in FIGs. 1 and 2. FIG. 1 shows the radiation intensity from a black body as a function of the temperature and the wavelength of the radiation.

The energy flux for a certain temperature and a certain wavelength range can be calculated from this curve by integrating it over the desired wavelength range. FIG. 2 shows the radiation intensity for an actual surface. As will be seen from the figure, the energy flux emitted by an actual surface is always less than that emitted by a black surface, i.e. the value of ϵ is less than unity. For the whole wavelength range, the energy flux emitted from the surface is

$$E_e = \epsilon_1 \cdot \sigma \cdot T_1^4 \quad (1)$$

FIG. 1

Strålningsintensitet
Radiation intensity

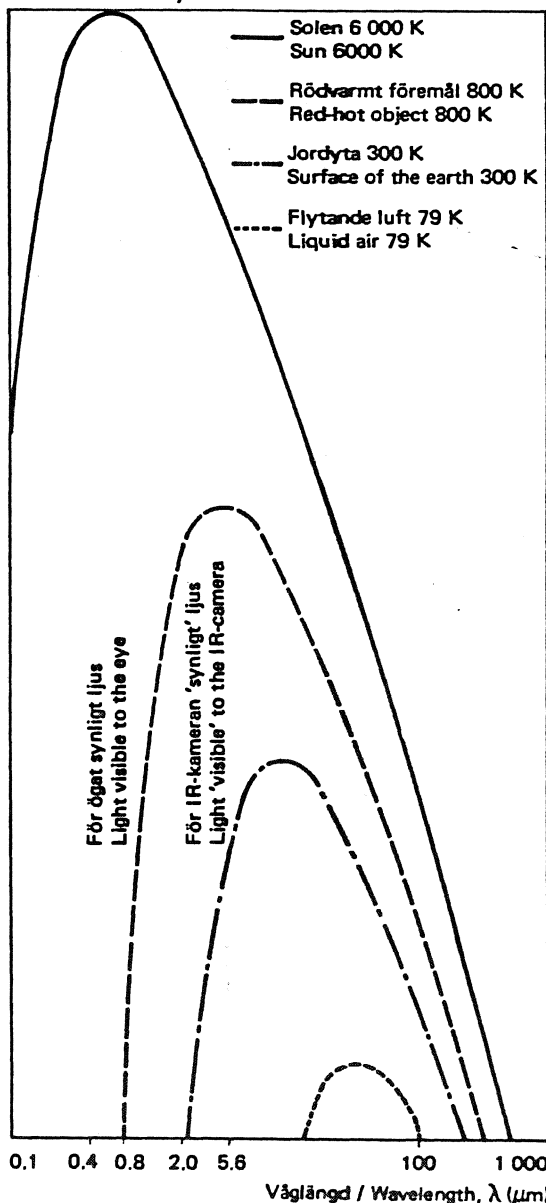


FIG. 1. Strålningsintensiteten för en absolut svart kropp vid olika temperaturer som funktion av våglängden med de för ögat (0,37–0,75 μm) och IR-kameran (2,0–5,6 μm) känsliga våglängdsområdena angivna.

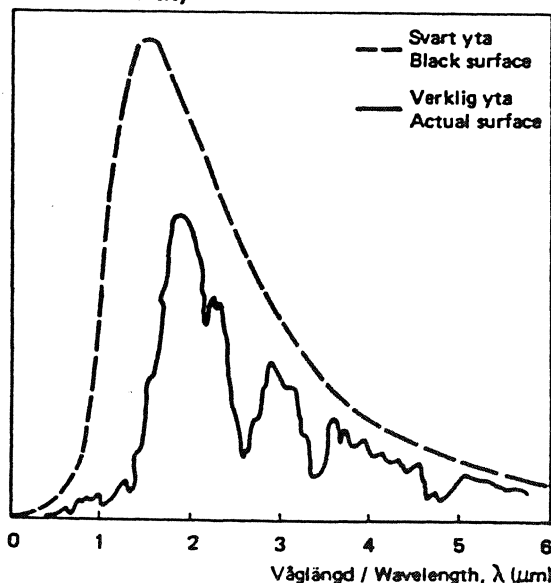
Intensity of radiation emitted by an ideal black body at different temperatures as a function of the wavelength range to which the eye (0.37–0.75 μm) and the IR-camera (2.0–5.6 μm) are sensitive.

FIG. 2. Jämförelse mellan strålningsspektrum för en absolut svart kropp och en verklig yta vid en temperatur av ca 1 900 K.

Comparison of the radiation spectrum for an ideal black body and that of an actual surface at a temperature of approx. 1900 K.

FIG. 2

Strålningsintensitet
Radiation intensity



»svart» kropp som funktion av temperatur och strålningens våglängd.

Energiflödet för viss temperatur och visst våglängdsområde kan beräknas ur denna kurva genom integration över önskat våglängdsområde. I FIG. 2 visas strålningsintensiteten för en verklig yta. Som framgår av figuren är det utstrålade energiflödet för en verklig yta alltid mindre än för en svart yta, dvs. ϵ -värdet är mindre än 1. Det från ytan utstrålade energiflödet för hela våglängdsområdet är:

$$E_e = \epsilon_1 \cdot \sigma \cdot T_1^4 \quad (1)$$

där

E_e emitterat energiflöde per ytenhet W/m^2
 σ Stefan-Bolzmanns konstant = $5,67 \cdot 10^{-8} \text{ W/m}^2, \text{K}^4$

T_1 ytans temperatur, K

ϵ_1 ytans emissionstal

Till strålningen från ytan adderas i praktiken ytterligare en energiflödespost, nämligen den del av till ytan instrålade energiflöde från omgivande ytor, som återreflekteras av ytan. Det återreflekterade energiflödet blir:

$$E_r = \rho_1 \cdot \epsilon_2 \cdot \sigma \cdot T_2^4 \quad (2)$$

där

E_r reflekterat energiflöde, W/m^2

ρ_1 ytans reflektionstal

T_2 omgivningens temperatur, K

ϵ_2 omgivningens emissionstal

Enligt Kirchhoffs lag gäller approximativt

$$\rho_1 = 1 - \epsilon_1 \quad (3)$$

Det från ytan utgående energiflödet blir då totalt:

$$E = E_e + E_r \text{ eller}$$

$$E = \epsilon_1 \cdot \sigma \cdot T_1^4 + (1 - \epsilon_1) \cdot \epsilon_2 \cdot \sigma \cdot T_2^4 \quad (4)$$

Kunde man uppmäta energiflödet E och om ϵ_1 , ϵ_2 och T_2 vore kända skulle man medelst ekv. (4) kunna få ett mått, T_1 , på en ytas temperatur.

Tillvägagångssättet beskrivs närmare nedan.

2.2 Principen för infrarödkameran

För ytor med temperaturer omkring 20°C , dvs. det temperaturområde som är av intresse inom byggnadstekniken var bestämning av utstrålad energi tidigare inte tekniskt möjlig då man endast hade tillgång till kameror och filmtyper som utnyttjade synligt ljus. Det mycket begränsade våglängdsområdet som utgör det för ögat synliga ($0,37-0,75 \mu\text{m}$) framgår av FIG. 1. I och med utveckling av infrarödtekniken har man emellertid numera skaffat sig hjälpmedel att »se» även inom det för ögat osynliga strålningsområdet. Man kan med andra ord uppmäta utstrålat energiflöde från föremål med en temperatur långt under 530°C (rödvarme), den tidigare lägsta »synliga temperaturen». De moderna infrarödkamerorna, med känslighetsområde $2-5,6 \mu\text{m}$, är försedda med ett

where

E_e Energy flux emitted per unit area, W/m^2

σ Stefan-Bolzmann constant = $5.67 \cdot 10^{-8} \text{ W/m}^2, \text{K}^4$

T_1 Temperature of the surface, K

ϵ_1 Emissivity of the surface

In practice, another item of energy flux must be added to the radiation emitted from the surface, that part of the energy flux received by the surface from the surrounding surfaces which is re-emitted by the surface. The re-emitted energy flux is

$$E_r = \rho_1 \cdot \epsilon_2 \cdot \sigma \cdot T_2^4 \quad (2)$$

where

E_r Energy flux reflected, W/m^2

ρ_1 Reflective index of the surface

T_2 Temperature of the surroundings, K

ϵ_2 Emissivity of the surroundings

Kirchhoff's law states the following approximate relationship

$$\rho_1 = 1 - \epsilon_1 \quad (3)$$

The total energy flux emitted by the surface is therefore

$$E = E_e + E_r \text{ eller}$$

$$E = \epsilon_1 \cdot \sigma \cdot T_1^4 + (1 - \epsilon_1) \cdot \epsilon_2 \cdot \sigma \cdot T_2^4 \quad (4)$$

If it were possible to measure the energy flux E and if ϵ_1 , ϵ_2 and T_2 were known, it would be possible by means of Equation (4) to obtain a measure, T_1 , of the temperature of a surface.

The procedure is described in greater detail in the following.

2.2 The principle of the infrared camera

Determination of the energy emitted by surfaces with a temperature of around 20°C , i.e. the temperature range which is of interest in building technology, was not technically feasible before since only cameras and types of film which utilized visible light were available. The very limited wavelength range which is visible to the human eye ($0.37-0.75 \mu\text{m}$) is shown in FIG. 1. Owing to the development of the infrared technique, however, means are now available which enable us to »see» even within the radiation range which is invisible to the eye. In other words, it is now possible to measure the energy flux emitted by an object with a temperature very much below 530°C (red heat) which was previously the lowest visible temperature. Modern infrared cameras with a sensitivity range of $2-5.6 \mu\text{m}$ are provided with a scanning system which makes possible the measurement of the individual energy fluxes emitted by a large number of partial elements of a surface, and in this way a radiation image of the surface as a whole can be constructed.

There are at present about a dozen commercial infrared equipments with a scanning system, among

bildavsökningssystem som möjliggör uppmätning av den individuella energiutstrålningen från ett stort antal delelement av en yta och kameran kan därigenom bygga upp en »strålningsbild» av ytan.

Det förekommer f.n. ett tiotal kommersiella infrarödutrustningar med bildavsökning, däribland två svenska, nämligen från AB AGA och AB Bofors. En infrarödutrustning består dels av en *kameraenhet* för avsökning och uppmätning av strålningen, dels av en *bildenhet* för åskådliggörande av mätresultatet i form av en värmebild (termogram), Borg (1968) och Sundström (1968).

Kameran har två uppgifter: bildavsökning och omvandling av den fokuserade infrarödstrålningen till en elektrisk signal (videosignal).

Avsökningen kan arrangeras på följande sätt, se FIG. 3. Den infallande strålningen reflekteras av en sfärisk spegel mot en oscillerande planspegel, vilken ger en vertikal avsökning av bilden. Planspegeln reflekterar strålningen mot en roterande, genomskinlig prisma, vilken horisontalavsöker bilden som därefter fokuseras på kamerans IR-detektor för omvandling till videosignal.

Apparaten avsöker och fokuserar kontinuerligt flera bilder per sekund innehållande ca 10 000 bildelement vardera. Detta ger en detaljrik »värmebild» eller »termogram». Som detektor i de flesta IR-kameror användes indiumantimonid (InSb) som vid 77 K är känslig inom våglängdsområdet 0–5,6 μm . Kamerans undre gränsvåglängd bestäms dock av germaniumlinser i kameran till 2 μm . IR-kamerans känslighetsområde anges på diagrammet i FIG. 1.

Den från kameran utgående videosignalen omvandlas av bildenheten, en katodstråleoscillograf, till en värmebild med »gråtonsskala». På oscillografens bildskärm erhålls därvid en gråtonsbild som anger ytans temperaturfördelning enligt gråtonsskalan (FIG. 4b). Den horisontella skalan på termogrammets nedre del är en kontinuerlig gråtonsskala från svart till vitt. Skalan är indelad i tio delstreck från noll till ett. Den vänstra och högra vertikala skalan anger IR-kamerans olika mätområden (1–1000 isotermenheter). Aktuellt mätområde anges av den svarta slitsens läge på den vertikala skalan (här 10).

them two Swedish ones, those made by AB AGA and AB Bofors. An infrared equipment consists of a *camera unit* for the scanning and measurement of the radiation and a *display unit* for illustration of the results of measurement in the form of a thermal image (thermogram), Borg (1968) and Sundström (1968).

The camera has two duties, that of scanning the object and converting the focussed infrared radiation into an electrical signal (video signal).

Scanning can be arranged in the way shown in FIG. 3. The incident radiation is reflected by a spherical mirror towards an oscillating plane mirror which scans the image vertically. The plane mirror reflects the radiation towards a rotating translucent prism which scans the image horizontally, and the image is then focussed on the IR-detector of the camera and converted into a video signal.

The apparatus continuously scans and focusses several frames per second, each containing about 10,000 picture elements. This produces a greatly detailed thermal image or thermogram. The detector used in most IR-cameras is indium antimonide (InSb) which at 77 K is sensitive within the wavelength range 0–5.6 μm , but the lower limiting wavelength of the camera is set by the germanium lenses in the camera at 2 μm . The sensitivity range of the IR camera is shown in the diagram in FIG. 1.

The video signal emitted by the camera is converted by the display unit, a cathode ray oscillograph, into a thermal image with a grey scale. A monochrome image which indicates the temperature distribution of the surface according to the grey scale (FIG. 4b) is thus obtained on the screen of the oscillograph. The horizontal scale on the lower part of the thermograph is a continuous grey-tone scale ranging from black to white. The scale is divided up into ten sections from 0 to 1. The right-hand and left-hand vertical scales indicate the different measuring ranges covered by the IR-camera (1–1000 isotherm units). The measuring range being dealt with is indicated by the position of the black slit on the vertical scale (in this case 10).

In the thermal image, the density is a function of

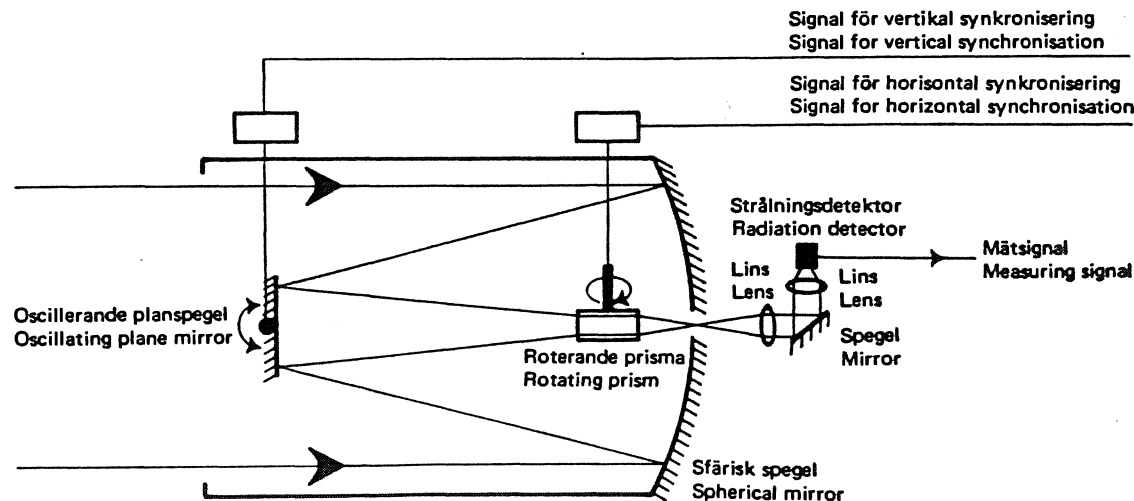


FIG. 3. Principskiss för strålgången i en IR-kamera.

Sketch showing path of rays in an IR-camera.

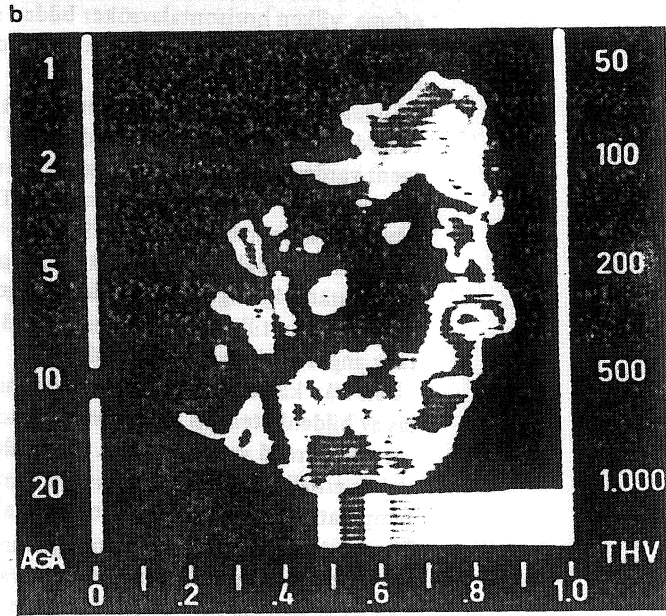
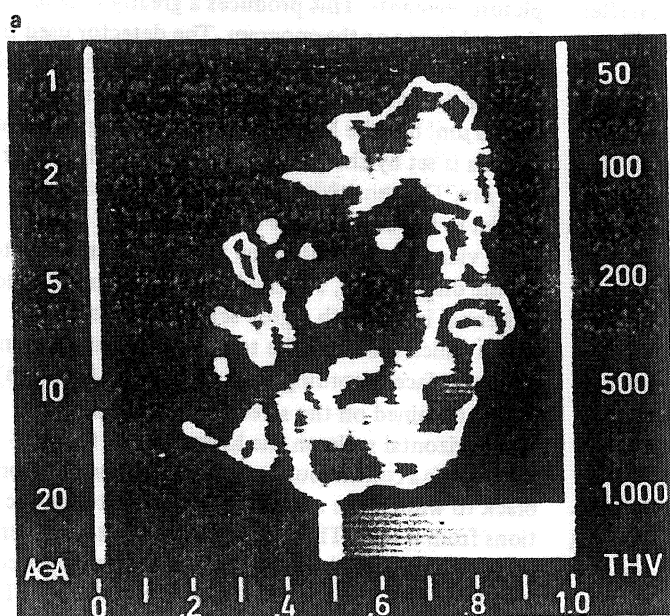
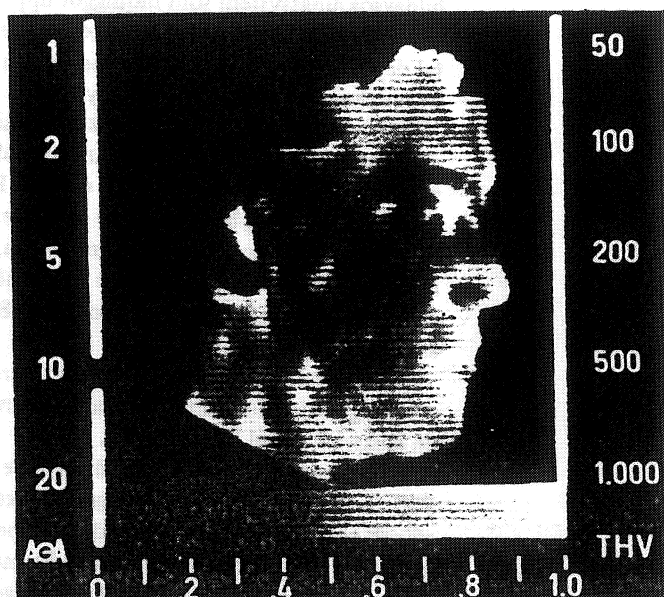


FIG. 4. Fotografi samt olika typer av termogram för samma mätobjekt.

Photograph and different types of thermogram of the same object.

a. Fotografi.
Photograph.

b. Termogram. Inga isotermer inlagda (gråtonsbild).
Thermogram. No imposed isotherm (monochrome image).

c. Termogram med en isotermmarkering (isoterm-bild).
Thermogram with one isotherm marking (isotherm image).

d. Termogram med två isotermmarkeringar (isoterm-bild).
Thermogram with two isotherm markings (isotherm image).

I värmebilden är svärtningsgraden en funktion av den utstrålade energin och därmed temperaturen hos den undersökta ytans olika partier. IR-kamerans temperaturområde är ca -30°C till $+2000^{\circ}\text{C}$. I närheten av $+30^{\circ}\text{C}$ mäter kameran temperaturen med en upplösning som är bättre än $0,2^{\circ}\text{C}$. För underlättande av uppmätning av temperaturskillnader mellan olika ytpartier inom värmebilden har IR-kameran försetts med en s.k. isotermmfunktion. Med hjälp av denna kan ytpartier inom värmebilden med samma temperatur bringas att lysa upp — isotermer uppstår i bildfältet och man får en isotermbild (FIG. 4c). Isothermer kan förläggas på valfri temperatur och öppna varierande temperaturområde inom bilden. Vissa kameratyper är utrustade med två isotermmfunktioner (FIG. 4d) för underlättande av temperaturdifferensavläsning.

Den åskådliggjorda temperaturnivån bestäms av isotermmarkeringens (vit spalt) läge på bildens gråtonsskala. Isothermfunktionen kan användas dels vid överlagsmässig kontroll av temperaturfördelningen på en yta dels för att bestämma skillnaden i ytemperatur

energy emitted and therefore also of the temperature of the different parts of the surface under examination. The temperature range of the IR-camera is approximately -30°C to $+2000^{\circ}\text{C}$, and near $+30^{\circ}\text{C}$ the camera measures the temperature with a resolution that is better than 0.2°C . In order to facilitate measurement of differences in temperature between different parts of the surface in the thermograph, the IR-camera has been equipped with an isotherm function. With the aid of this, parts of the surface which have the same temperature can be made to glow in the thermograph — isotherms are imposed on the frame and an isotherm image is obtained (FIG. 4c). The isotherms can be set at any temperature and a variable temperature range can be covered in the image. Some types of camera are equipped with two isotherm functions (FIG. 4d) in order to facilitate determination of temperature differences. The temperature level thus revealed is determined by the position of the isotherm marking (white) on the grey scale of the thermograph. The isotherm mechanism

mellan valda punkter på den betraktade ytan. I termogrammets gråtonskala (nederst) kan skillnaden mellan isothermmarkeringarna avläsas. Multiplieras detta värde med aktuellt mätområde (se den svarta slitsen) erhålls isothermskillnaden i isothermenheter. Motsvarande skillnad i celciusgrader ($^{\circ}\text{C}$) erhålls om aktuella värden insätts i kamerans kalibreringsfunktion (se exempel i kapitel 2.3).

I FIG. 4d kan man avläsa en skillnad av ca 0,1 mellan isothermmarkeringarna. Multiplikation med 10 ger då isothermskillnaden 1 i isothermenheter. Om man antar att emissionstalet för hud är ungefär 1 och att hudens ytemperatur är ca 30°C blir den verkliga temperaturskillnaden mellan isothermerna ca 1°C .

Med hjälp av en särskild teknik, som beskrivs i resp. kameratillverkarens instruktionsbok, kan även färgtermogram framställas där varje färgton motsvarar ett visst temperaturintervall. God åskådighet av temperaturfördelningen uppnås på detta sätt. Som exempel se färgbilden på omslagets framsida. Samma figur visas i svart-vitt i FIG. 5.

Som ovan angivits bestämmer IR-kameran endast *relativa temperaturskillnader* inom bildfältet. Önskar man bestämma absolut temperaturfördelning för den undersökta ytan erfordras dels kännedom om sann temperatur i en referenspunkt inom mätytan, dels emissionstalet för referensytan och hela mätobjektet, dels slutligen kamerans s.k. temperaturfunktion och kalibreringskurvor. Nedan redogörs för principen för kvantitativ bestämning av en temperaturfördelning medelst termografering.

2.3 Bestämning av absolut temperaturfördelning medelst IR-kamera

Vi börjar med att härleda sambandet mellan på kamerans skärm uppmätt skillnad mellan isothermvärden och motsvarande sann temperaturskillnad.

Från en yta med temperaturen T_1 och emissionstalet ϵ_1 utstrålar enligt ekv. 4 följande energiflöde om omgivande (motstrålande) ytor har temperaturen T_R och emissionstalet ϵ_R :

$$E_1 = \epsilon_1 \cdot \sigma \cdot T_1^4 + (1 - \epsilon_1) \epsilon_R \cdot \sigma \cdot T_R^4 \quad (5)$$

Befinner sig vid termografering dessutom en delyta

can either be used in general control of the distribution of temperature over a given surface or to determine the difference in surface temperature between the points selected on the surface studied. The difference between the isotherm markings can be read off on the thermograph's grey scale (bottom). If this value is multiplied by the value for the current area of study (see the black slit), the isotherm differential in terms of isotherm units can be obtained. The corresponding difference in degrees Celcius ($^{\circ}\text{C}$) is obtained if the current values are inserted in the camera's calibration mechanism (see example in Chapter 2.3).

A difference of about 0.1 between isotherm markings can be read off in FIG. 4d. Multiplication by 10 then gives an isotherm difference of 1 in isotherm units. If it is assumed that the emissivity of skin is about 1 and that the surface temperature is approximately 30°C the actual difference in temperature between isotherms is about 1°C .

By using a special technique which is described in the instruction manual of the camera manufacturer in question, it is also possible to produce colour thermograms in which every shade of colour corresponds to a certain temperature interval. The temperature distribution is illustrated very clearly in this way. For illustration see the figure on the front cover. The same figure is shown in black and white in FIG. 5.

As stated above, the IR-camera determines only the *relative temperature differences* in the image. If it is required to determine the absolute temperature distribution over the surface being studied, it is necessary to know the true temperature of a point of reference inside the measurement surface, the emissivity of the reference surface and of the whole object of measurement, and the temperature function and calibration curves of the camera. The principle of quantitative determination of the temperature distribution by means of thermography is described below.

2.3 Determination of the absolute temperature distribution using an IR-camera

We will begin by deriving the relationship between the difference between the isotherm values measured on the screen of the camera and the corresponding true temperature difference.

If the surrounding (reflecting) surfaces have a temperature T_R and emissivity ϵ_R , then according to Equation (4) the following energy flux will be emitted from a surface with a temperature of T_1 and emissivity ϵ_1 :

$$E_1 = \epsilon_1 \cdot \sigma \cdot T_1^4 + (1 - \epsilon_1) \epsilon_R \cdot \sigma \cdot T_R^4 \quad (5)$$

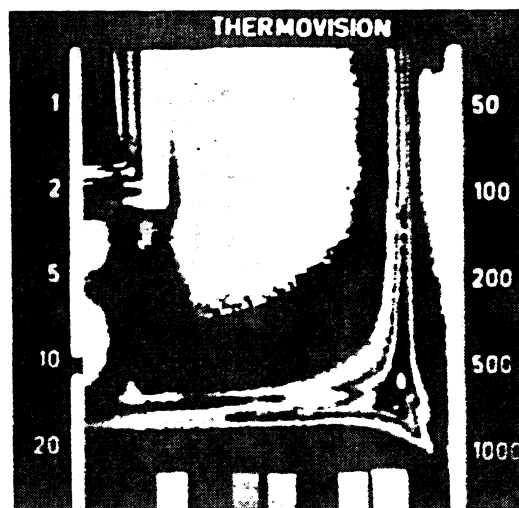
If during thermography there is also a partial surface with the temperature T_2 and emissivity ϵ_2 within the field of view, then the following relationship is obtained for this partial surface in the same way:

$$E_2 = \epsilon_2 \cdot \sigma \cdot T_2^4 + (1 - \epsilon_2) \epsilon_R \cdot \sigma \cdot T_R^4 \quad (6)$$

If isotherms are imposed over the two partial surfaces with temperature T_1 and T_2 , the isotherm difference measured on the screen of the camera, ΔI_{12} , will have the following value:

FIG. 5. Färgtermogram av väggparti vid golvhörn. Den vertikala skalan anger IR-kamerans olika mätområden (1–1 000 isothermenheter). Den svarta slitsen i mät-skalan anger det aktuella mätområdet (10). Varje färgton motsvarar ett visst temperaturområde.

Colour thermogram of portion of wall at corner of floor. The vertical scale indicates the different ranges of measurement of the IR-camera (1–1000 isotherm units). The black slit in the scale indicates the range of measurement in use (10). Each shade of colour corresponds to a certain temperature range.



med temperaturen T_2 och emissionstalet ϵ_2 inom bildfältet fås på samma sätt för denna delyta:

$$E_2 = \epsilon_2 \cdot \sigma \cdot T_2^4 + (1 - \epsilon_2) \epsilon_R \cdot \sigma \cdot T_R^4 \quad (6)$$

Förläggs isotermer över de båda delytorna med temperaturen T_1 resp. T_2 får den på kamerans bildskärm uppmätta isotermskillnaden ΔI_{12} följande värde:

$$\Delta I_{12} = k \cdot (E_1 - E_2) \quad (7)$$

där k är en konstant som beror av kamerans egenskaper.

Med värden från ekv. (5) och (6) insatta i ekv. (7) fås

$$\Delta I_{12} = k \left[\epsilon_1 \cdot \sigma \cdot T_1^4 + (1 - \epsilon_1) \cdot \epsilon_R \cdot \sigma \cdot T_R^4 - \epsilon_2 \cdot \sigma \cdot T_2^4 - (1 - \epsilon_2) \cdot \epsilon_R \cdot \sigma \cdot T_R^4 \right] \quad (8)$$

Väljes $\epsilon_R = 1$ fås

$$\Delta I_{12} = k \cdot \epsilon_1 \cdot \sigma \cdot (T_1^4 - T_R^4) - k \cdot \epsilon_2 \cdot \sigma \cdot (T_2^4 - T_R^4) \quad (9)$$

$$\text{Sättes } k \cdot \sigma \cdot (T^4 - T_R^4) = f(T) \quad (10)$$

fås

$$\Delta I_{12} = \epsilon_1 \cdot f(T_1) - \epsilon_2 \cdot f(T_2) \quad (11)$$

Funktionen $f(T)$ kan bestämmas experimentellt och framgår för kameran AGA 680 av FIG. 6 (en särskild kurva gäller för varje objektivapertur).

Överensstämmer den vid ett valfritt mättillfälle rådande omgivningstemperaturen (motstrålningstemperaturen) T_A ej med den valda referenstemperaturen vid kamerans kalibrering, T_R fås

$$\Delta I_{12} = \epsilon_1 \cdot \left[f(T_1) - f(T_A) \right] - \epsilon_2 \cdot \left[f(T_2) - f(T_A) \right] \quad (12)$$

Löses $f(T_1)$ ur ekv. (12) fås

$$f(T_1) = \frac{\Delta I_{12}}{\epsilon_1} + \frac{\epsilon_2}{\epsilon_1} \cdot f(T_2) + \left(1 - \frac{\epsilon_2}{\epsilon_1}\right) f(T_A) \quad (13)$$

$$\Delta I_{12} = k \cdot (E_1 - E_2) \quad (7)$$

where k is a constant which is dependent on the properties of the camera.

If the values in Equation (5) and (6) are substituted into Equation (7), we have

$$\Delta I_{12} = k \left[\epsilon_1 \cdot \sigma \cdot T_1^4 + (1 - \epsilon_1) \cdot \epsilon_R \cdot \sigma \cdot T_R^4 - \epsilon_2 \cdot \sigma \cdot T_2^4 - (1 - \epsilon_2) \cdot \epsilon_R \cdot \sigma \cdot T_R^4 \right] \quad (8)$$

If ϵ_R is put equal to unity, we have

$$\Delta I_{12} = k \cdot \epsilon_1 \cdot \sigma \cdot (T_1^4 - T_R^4) - k \cdot \epsilon_2 \cdot \sigma \cdot (T_2^4 - T_R^4) \quad (9)$$

$$\text{If we put } k \cdot \sigma \cdot (T^4 - T_R^4) = f(T) \quad (10)$$

we have

$$\Delta I_{12} = \epsilon_1 \cdot f(T_1) - \epsilon_2 \cdot f(T_2) \quad (11)$$

The function $f(T)$ can be determined experimentally and is shown for the camera AGA 680 in FIG. 6

(there is a separate curve for each objective aperture).

If the ambient temperature (counter-reflection temperature) T_A which prevails during a time when a measurement is carried out is not the same as the reference temperature T_R chosen during calibration of the camera, we have

$$\Delta I_{12} = \epsilon_1 \cdot \left[f(T_1) - f(T_A) \right] - \epsilon_2 \cdot \left[f(T_2) - f(T_A) \right] \quad (12)$$

If Equation (12) is solved for $f(T_1)$, we have

$$f(T_1) = \frac{\Delta I_{12}}{\epsilon_1} + \frac{\epsilon_2}{\epsilon_1} \cdot f(T_2) + \left(1 - \frac{\epsilon_2}{\epsilon_1}\right) f(T_A) \quad (13)$$

where

T_1 Temperature at point 1 on the object of measurement

T_2 Temperature at point 2 on the object of measurement

T_A Ambient temperature

ϵ_1 Emissivity at point 1 on the object of measurement

ϵ_2 Emissivity at point 2 on the object of measurement

ΔI_{12} Difference in isotherm units between the isotherm markings in the grey scale for points 1 and 2 on the screen

$f(T_1)$ Value of the function according to the calibration curve of the camera for T_1

$f(T_2)$ Value of the function according to the calibration curve of the camera for T_2

$f(T_A)$ Value of the function according to the calibration curve of the camera for T_A

If the quantities on the right-hand side of Equation (13) are known, $f(T_1)$ can be calculated. The value

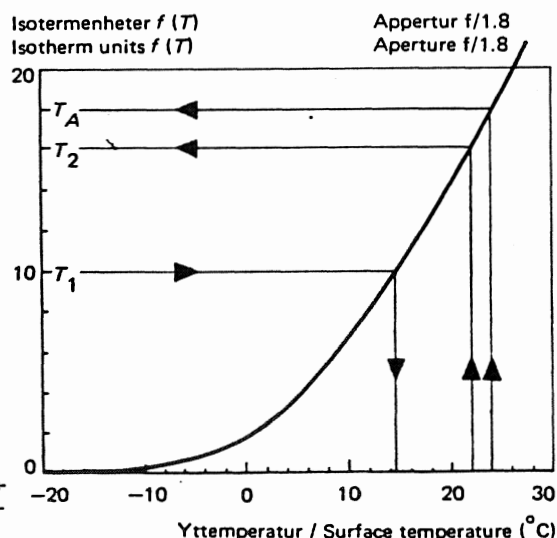


FIG. 6. Kalibreringskurva med inlagt tillämpningsexempel för AGA THV 680 (se texten).

Calibration curve with example showing application to the AGA THV 680 camera (see the body of the report).

där	
T_1	Temperatur i punkt 1 på mätobjektet
T_2	Temperatur i punkt 2 på mätobjektet
T_A	Omgivningens temperatur
ϵ_1	Emissionstal i punkt 1 på mätobjektet
ϵ_2	Emissionstal i punkt 2 på mätobjektet
ΔI_{12}	Skilnad i isothermenheter mellan isothermmarkeringarna på gråtonskalan för punkt 1 och 2 på bildskärmen
$f(T_1)$	Funktionsvärdet för T_1 enligt kamerans kalibreringskurva
$f(T_2)$	Funktionsvärdet för T_2 enligt kamerans kalibreringskurva
$f(T_A)$	Funktionsvärdet för T_A enligt kamerans kalibreringskurva
Är storheterna på högra sidan av ekv. (13) kända kan $f(T_1)$ beräknas. T_1 kan därefter avläsas ur kamerans kalibreringsdiagram (se FIG. 6).	

Exempel

Antag att

$$t_2 = 22^\circ\text{C} \quad [T = (t + 273) \text{ K}]$$

$$t_A = 24^\circ\text{C}$$

$$\epsilon_1 = 0,85$$

$$\epsilon_2 = 0,97$$

$$\Delta I_{12} = -5 \text{ isothermenheter}$$

$$t_1 \text{ söks}$$

Ur kalibreringsdiagrammet i FIG. 6 fås

$$f(t_2) = 16,2 \text{ isothermenheter}$$

$$f(t_A) = 18,0 \text{ isothermenheter}$$

Insätts de kända uppgifterna i ekv. (13) fås

$$f(t_1) = \frac{-5}{0,85} + \frac{0,97}{0,85} \cdot 16,2 + (1 - \frac{0,97}{0,85}) \cdot 18,0$$

$$f(t_1) = -5,9 + 18,4 - 2,5 = 10,0$$

Ur FIG. 6 fås $t_1 = 14,6^\circ\text{C}$

Ekv. (13) kan även användas för bestämning av emissionstalet ϵ_1 för en yta om ytans temperatur T_1 och de övriga storheterna i uttrycket är kända (se nedan).

2.4 Uppmätning av emissionstal för byggnadsmaterial

Som tidigare framhållits varierar emissionstalet (ϵ -värdet) för olika material med såväl temperatur som strålningens våglängd. Emissionstalets variation med temperaturen kan försummas inom det för byggnadsmaterial aktuella temperaturområdet (omkring $-20^\circ\text{C} - +30^\circ\text{C}$), medan beroendet av våglängden måste beaktas. Emissionstalet anges för olika material i standardtabeller. Värdet anges dels för vissa distinkta våglängder, dels som ett totalvärde för hela våglängdsområdet.

Eftersom IR-kameran endast kan uppmäta strålningen inom våglängdsområdet $2-5,6 \mu\text{m}$ är det av

of T_1 can then be read off the calibration diagram of the camera (see FIG. 6).

Example

Assume that

$$t_2 = 22^\circ\text{C}$$

$$t_A = 24^\circ\text{C}$$

$$\epsilon_1 = 0.85$$

$$\epsilon_2 = 0.97$$

$$\Delta I_{12} = -5 \text{ isotherm units}$$

The value of t_1 is required.

From the calibration diagram in FIG. 6,

$$f(t_2) = 16.2 \text{ isotherm units}$$

$$f(t_A) = 18.0 \text{ isotherm units}$$

If the known information is substituted into Equation (13), we have

$$f(t_1) = \frac{-5}{0.85} + \frac{0.97}{0.85} \cdot 16.2 + (1 - \frac{0.97}{0.85}) \cdot 18.0$$

$$f(t_1) = -5.9 + 18.4 - 2.5 = 10.0$$

From FIG. 6, $t_1 = 14.6^\circ\text{C}$

Equation (13) can also be used for determination of the emissivity ϵ_1 of a surface if the temperature T_1 of the surface and the other quantities in the expression are known, see below.

2.4 Measurement of the emissivity of building materials

As pointed out before, the emissivity ϵ of different materials varies both with the temperature and the wavelength of the radiation. The variation in the value of the emissivity with the temperature can be ignored within the temperature range of interest for building materials (from about -20°C to $+30^\circ\text{C}$), but the variation with the wavelength must be taken into account. The emissivity for different materials is tabulated in standard tables, where it is stated both for certain distinct wavelengths and also in terms of an overall value for the whole wavelength range.

Since the IR-camera can only measure radiation within the wavelength range $2-5.6 \mu\text{m}$, it is of interest that values of the emissivity for this range should be determined for building materials. It is these values of the emissivity which should primarily be used in determining the temperature distribution in the thermogram.

A preliminary investigation has been carried out at the Heating and Ventilating Laboratory of the National Swedish Institute for Materials Testing in order to determine values of the emissivity applicable for the IR-camera for a number of common building materials. The principle described in Section 2.3 was applied during the procedure, the value of ϵ being calculated from Equation (13). (Equation (13) was solved for ϵ_1 .) The investigation was performed in a climatic installation equipped with a test room

intresse att ϵ -värdet för detta område fastställs för byggnadsmaterial. Det är dessa ϵ -värden som i första hand bör användas vid bestämning av temperaturfördelningen i termogrammen.

Vid Statens provningsanstalts VVS-laboratorium har en orienterande undersökning utförts för att fastställa för IR-kameran tillämpliga ϵ -värden på ett antal vanliga byggnadsmaterial. Vid bestämningen tillämpades den princip som beskrivits under 2.3, varvid ϵ -värdet beräknas ur ekv. (13). (ϵ_1 i ekv. (13) söks.) Undersökningen utfördes i en klimatanläggning försedd med ett mättrum och ett klimatrums, båda temperaturreglerade och åtskilda genom en skiljevåg av cellplast (se FIG. 7).

Mättrumets strålningsegenskaper valdes så att de i stort motsvarade ett bostadsrum. Strålningsegenskaperna definierades av följande förhållanden: väggar och tak var målade med oljefärg och golvet täcktes av korkmatta. Väggarnas, takets och golvet's ytemperatur var konstant och omkring 20°C . Under mätningens gång vistades en person i rummet nära kameran. Värmekällan i mättrummet placerades bakom en strålningsskyddad aluminiumplåt, FIG. 8. Tjugofyra provytor med dimensionerna $20 \times 20 \text{ cm}$ fästes sedan i därtill avsedda hål i skiljeväggen (se FIG. 9) mellan mättrum och klimatrums. Mätningarna utfördes vid tre olika värden på provernas ytemperatur. Ytemperaturen reglerades genom inställning av klimatrums temperaturen på lämpliga värden. Det sökta ϵ -värdet anges som medelvärdet av de tre försöksresultaten. Vid mätningarna riktades värmekameran vinkelrätt mot respektive provyta, på ett avstånd av 2 m från provväggen (se FIG. 7). En temperaturreferens typ AGA modell 1010 användes. Referensen var vid varje exponering placerad på provväggen i kamerans bildfält, se FIG. 10.

Temperaturreferensens ytemperatur var reglerbar från $+16^\circ\text{C}$ – $+100^\circ\text{C}$ med en noggrannhet av $\pm 0,2^\circ\text{C}$ och med en korttidsstabilitet (1 tim.) av $0,02^\circ\text{C}$. Före användningen kalibrerades referensen mot en ekvivalent svartkroppstemperatur. (Detta innebär att om referensens temperatur inställs på no-

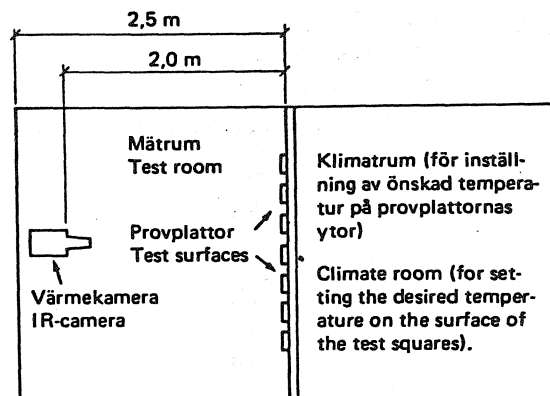


FIG. 7. Skiss av klimatanläggning med provvägg för emissionstalsbestämning (se även FIG. 8 och 9).

Sketch of climatic installation with test wall for determination of the emissivity (see also FIGs. 8 and 9).

and a climate room, both of which were under temperature control and were separated by a partition of cellular plastic (see FIG. 7).

The radiation properties of the test room were chosen in such a way that they approximated to those of a room inside a flat. The conditions which defined the radiation properties were that the walls and ceiling were painted with an oil paint and the floor was covered by a cork mat, and that the surface temperature of the walls, ceiling and floor were kept constant at around 20°C . One person was inside the room near the camera during the time measurements were carried out. The source of heat in the test room was placed behind a radiation-protected sheet of aluminium, FIG. 8. Twenty-four test surfaces measuring $20 \times 20 \text{ cm}$ were then mounted in holes provided for this purpose in the partition between the test room and the climate room (see FIG. 9). Readings were taken for three different values of the surface temperature over the test surfaces, the different values being obtained by setting the temperature of the climate room at suitable values. The value of emissivity quoted is the mean of the three test results. During the measure-

FIG. 8. Bild av värmekällans placering i mättrummet.

Photograph showing placing of the source of heat in the test room.

FIG. 9. Uppmonterade provytor för emissionstalsbestämning.

Mounted test surfaces for determination of the emissivity.

FIG. 8

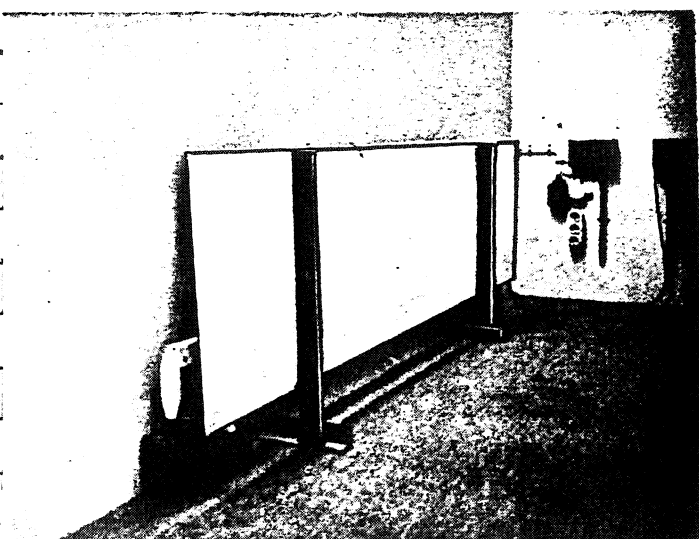


FIG. 9

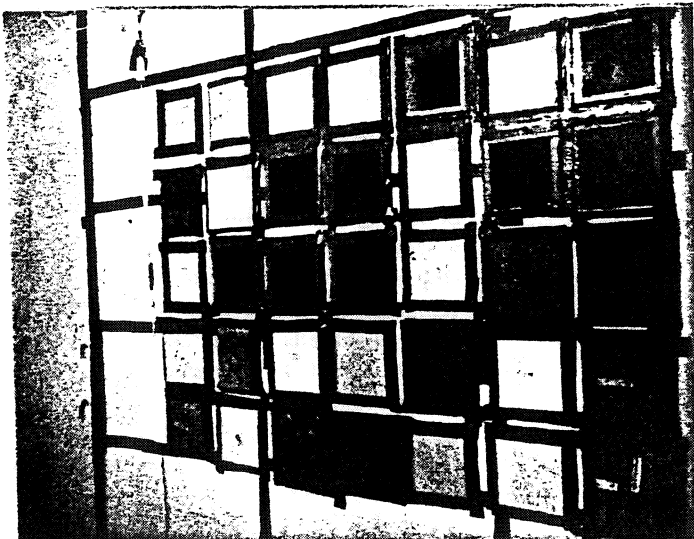
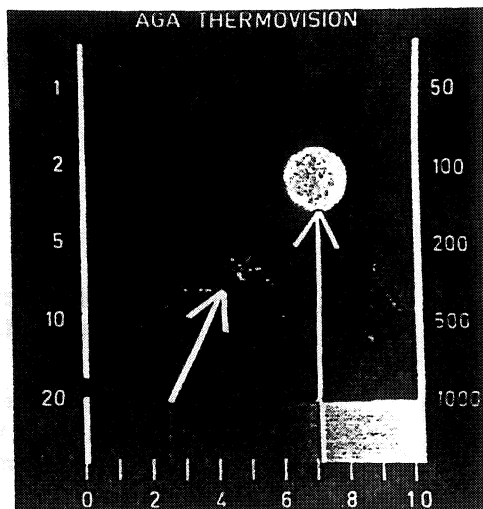
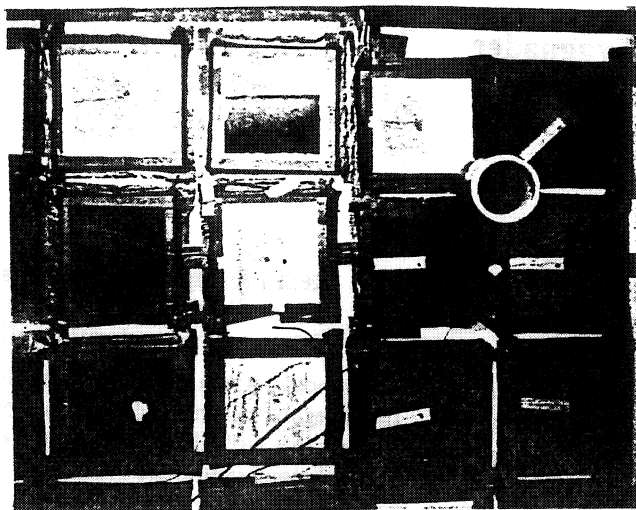


FIG. 10. Cirkulär temperaturreferens av typ AGA Modell 1010 placerad på provväggen.

Circular AGA Model 1010 temperature reference placed on the test wall.

FIG. 11. Isothermbild av provyta där det högre isothermvärdet (högra vita spalten på den horisontella skalan) motsvarar temperaturreferensens ytemperatur och det lägre isothermvärdet (vänstra spalten) motsvarar den kända ytemperaturen hos provytan.

Isotherm image of the test surface in which the higher isotherm value (the right-hand white bar on the horizontal scale) corresponds to the surface temperature of the temperature reference and the lower isotherm (the left-hand bar) corresponds to the known surface temperature of the test surface.



minellt 22°C , emitteras från referensen en strålning som motsvarar strålningen från en svart kropp med temperaturen 22°C .)

Kamerans isothermfunktion användes så att det ena isothermvärdet motsvarade referensens ytemperatur och det andra isothermvärdet provytans ytemperatur. Provytans absoluttemperatur bestämdes medelst termoelement (se FIG. 11).

Under mätserien registrerades ytemperaturerna på skrivare. Temperaturvariationen hos provytorna under mätserien var mindre än $0,2^{\circ}\text{C}$, vilket väl fyllde uppställda krav.

Mätresultat (se BIL. 1, TAB. 3)

Ur ekv. (13) erhålles om ϵ_2 sätts = 1

$$\epsilon_1 = \frac{\Delta I_{12} + f(T_2) - f(T_A)}{f(T_1) - f(T_A)} \quad (14)$$

De uppmätta emissionstalen anges i TAB. 3 och utgör medelvärden för tre mätningar vid olika ytemperaturer hos proverna.

ments, the infrared camera was positioned at a distance of 2 m from the test wall and was pointed at right angles towards the test surface in question (see FIG. 7). The AGA Model 1010 temperature reference used was placed on the test wall in the field of view of the camera during each exposure. See FIG. 10.

The surface temperature of the temperature reference could be regulated from $+16^{\circ}\text{C}$ to $+100^{\circ}\text{C}$ with an accuracy of $\pm 0.2^{\circ}\text{C}$ and with a short-term stability (1 hour) of 0.02°C . Prior to being used the reference was calibrated against an equivalent black body temperature. (This means that if the temperature of the reference is set at the nominal value of 22°C , the reference will emit radiation which corresponds to radiation emitted by a black body with a temperature of 22°C .)

The isotherm function of the camera was used in such a way that one isotherm value corresponded to the surface temperature of the reference and the other isotherm value to the surface temperature of the test surface. The absolute value of this temperature was determined using a thermocouple (see FIG. 11)

During the measurement series, the surface temperatures were recorded on a plotter. The variation in the temperature of the test surfaces during the test series was less than 0.2°C , which fully satisfied the requirements.

Measurement results: (see Appendix 1, TAB. 3)

If ϵ_2 is put = 1, the following is obtained from Equation (13):

$$\epsilon_1 = \frac{\Delta I_{12} + f(T_2) - f(T_A)}{f(T_1) - f(T_A)} \quad (14)$$

The values of emissivity measured are shown in TAB. 3 and are the means of the three measurements carried out at different surface temperatures over the test surfaces.

3.1 Samband mellan ytemperaturfördelning och värmemotstånd hos yttervägg

Som tidigare nämnts framträder ojämnheter i värmemotståndsfördelningen hos en vägg med olika ytter- och innertemperaturer som temperaturvariationer på väggens ytor. Det kan vara av intresse att närmare undersöka vilka faktorer som påverkar temperaturfördelningen på väggytan. Sambandet mellan en planparallell väggs värmemotstånd och ytemperatur kan härledas på följande sätt:

Temperaturfallet över en vägg vid endimensionellt värmefflöde räknat från luft till luft framgår av FIG. 12. Enligt värmeöverföringsteorin kan värmefflödet genom väggen i detta fall uttryckas genom följande ekvationer:

$$q = \frac{1}{m_i} (t_i - t_{oi}) \quad (15)$$

$$q = \frac{1}{m} (t_{oi} - t_{ou}) \quad (16)$$

$$q = \frac{1}{m_u} (t_{ou} - t_u) \quad (17)$$

$$q = \frac{1}{m_i + m + m_u} (t_i - t_u) \quad (18)$$

där

q Värmefflöde per ytenhet

m_i Värmeövergångsmotstånd vid väggens varma yta

3.1 Relationship between surface temperature distribution and the thermal resistance of an external wall

Reference has been made previously to the fact that irregularities in the distribution of thermal resistance in a wall which has different external and internal temperatures are manifested as temperature variations over the surfaces of the wall. It may be of interest to ascertain in greater detail which are the factors that affect temperature distribution over the surface of a wall. The relationship between the thermal resistance of a wall with two parallel plane surfaces and the surface temperature of such a wall can be derived in the following way:

The drop in temperature over a wall during single-dimensional heat flow from air to air is shown in FIG. 12. According to the theory of heat transmission, the heat flow through the wall in this case can be expressed by means of the following equations:

$$q = \frac{1}{m_i} (t_i - t_{oi}) \quad (15)$$

$$q = \frac{1}{m} (t_{oi} - t_{ou}) \quad (16)$$

$$q = \frac{1}{m_u} (t_{ou} - t_u) \quad (17)$$

$$q = \frac{1}{m_i + m + m_u} (t_i - t_u) \quad (18)$$

where

q Heat flow per unit area

m_i Surface resistance at the warm surface of the wall

m_u Surface resistance at the cold surface of the wall

m Thermal resistance of the wall

t_i Air temperature on the warm side

t_{oi} Surface temperature of the wall on the warm side

t_{ou} Surface temperature of the wall on the cold side

t_u air temperature on the cold side

If q is eliminated from Equations (15) and (18),

$$t_{oi} = t_i - \frac{m_i (t_i - t_u)}{m_i + m + m_u} \quad (19)$$

If q is eliminated from Equations (17) and (18),

$$t_{ou} = t_u + \frac{m_u (t_i - t_u)}{m_i + m + m_u} \quad (20)$$

It will be seen from Equations (19) and (20) that

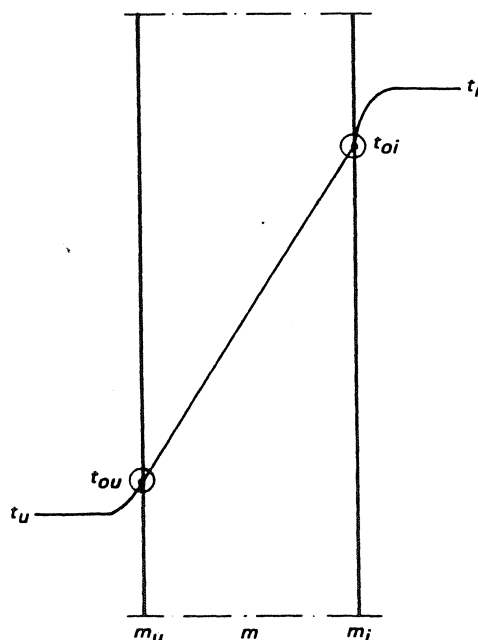


FIG. 12. Temperaturförlopp i vägg vid endimensionellt värmefflöde.

Drop in temperature over a wall in single-dimensional heat flow.

m_u	Värmeövergångsmotstånd vid väggens kalla yta
m	Väggens värmemotstånd
t_i	Lufttemperatur på varma sidan
t_{oi}	Väggens yttemperatur på varma sidan
t_{ou}	Väggens yttemperatur på kalla sidan
t_u	Lufttemperatur på kalla sidan

Elimineras q ur ekv. (15) och (18) fås

$$t_{oi} = t_i - \frac{m_i(t_i - t_u)}{m_i + m + m_u} \quad (19)$$

Elimineras q ur ekv. (17) och (18) fås

$$t_{ou} = t_u + \frac{m_u \cdot (t_i - t_u)}{m_i + m + m_u} \quad (20)$$

Av ekv. (19) och (20) framgår att väggens yttemperatur på varma sidan, t_{oi} respektive på kalla sidan, t_{ou} bestäms av väggens värmemotstånd, m , under förutsättning att de i uttrycken (19) och (20) ingående övriga storheterna, värmeövergångsmotstånden m_u och m_i och lufttemperaturen på den kalla och varma sidan, t_u och t_i är kända och konstanta såväl i tiden som i väggens plan. (Tillämpning av ekvationer för endimensionellt värmefflöde på en vägg med varierande värmemotstånd innebär en approximation som dock kan godtagas vid denna principdiskussion.)

Vid fältmätning av yttemperatur är övergångsmotstånden vid väggytan normalt ej kända. Följaktligen saknas möjligheter att med hjälp av enbart termografering bestämma väggens värmemotståndsfördelning kvantitativt. Däremot finns goda möjligheter att med termograferingens hjälp bilda sig en uppfattning om en relativ värmemotståndsfördelning för väggen och därmed *lokalisera* partier hos väggen som innehåller isolerfel. Vid denna lokalisering föreligger viss fara för förväxling av isolerfelsbetingade temperaturvariationer på väggytan med sådana som förorsakas av lokala variationer i värmeövergångsmotstånd, Adamson (1971).

Sådana lokala ändringar av övergångsmotstånd kan åstadkommas av luftströmning och värmestrålning från värmekällor. I hörnpartier har man exempelvis alltid andra övergångsmotstånd än på väggen i övrigt, eftersom geometriska förhållanden påverkar luftströmnings- och strålningsförlopp. Som framgår av redogörelse bl.a. under 3.4 och 5.35 kan man dock genom användning av typtermogram för typväggar och med erfarenhet av tidigare mätningar oftast mycket väl avgöra skillnaden mellan temperaturvariationer på väggytan betingade av byggfel och sådana som är betingade av skilda värmeövergångsmotstånd i olika väggpartier.

3.2 Samband mellan yttemperaturfördelning och luftläckage genom otätheter

Även isolerfel i form av otätheter kan upptäckas genom yttemperaturmätning. Vid undertryck i den undersökta byggnaden inströmmar uteluft till rummet. Uteluftströmmen genom smala öppningar »vidhäftan»

the surface temperatures t_{oi} and t_{ou} of the wall on the warm and cold sides respectively are determined by the thermal resistance (m) of the wall, on condition that the other quantities in the expressions (19) and (20), the surface resistances m_u and m_i and the air temperatures t_u and t_i on the cold and warm sides respectively are known and maintained constant both in time and along the plane of the wall. (Application of equations for single-dimensional heat flow to a wall with a variable thermal resistance entails an approximation which can however be accepted in this general discussion.)

During field measurements of the surface temperature, the surface resistances at the surfaces of the wall are generally unknown, and there is consequently no possibility of quantitatively determining the distribution of thermal resistance by thermography alone. On the other hand, however, the chances of forming an idea with the aid of thermography of the relative distribution of thermal resistance over the wall, and in this way *locating* parts of the wall which contain defects in insulation, are very good. In this location process there is some risk that temperature variations over the surface of the wall which are due to defects in insulation may be mistaken for variations which are caused by local variations in surface resistance, Adamson (1971).

Such local changes in surface resistance may be caused by air flow and thermal radiation from sources of heat. For instance, at corners the surface resistance is always different from that of other parts of the wall, since geometrical conditions affect air flow and radiation processes. As will be seen from Sections 3.4 and 5.35 and other Sections, however, it is very often possible by using typical thermograms for typical walls and on the basis of experience acquired during previous measurements, to distinguish clearly between temperature variations along the surface of the wall which are due to building defects and those caused by differences in surface resistance in different parts of the wall.

3.2 Relationship between distribution of surface temperature and ingress of air through small openings

Defects in insulation in the form of small openings can also be detected by measurements of surface temperature. If the pressure in the building being studied is below that outside, air will flow into the room. Since external air flowing through narrow openings usually adheres to adjacent parts of the wall and cools these down, cold wall portions of characteristic shape are formed. During thermography, the cold wall portions can be easily detected and any air flow measured by means of an anemometer. In the same way, when the pressure in the building being studied is higher than that outside, parts of the wall on the warm side, near points where the air in the room flows outwards, will become warmer.

vanligen på angränsande väggpartier och avkyler dessa. Följden blir att kalla väggpartier med karakteristisk form uppstår. Vid termografering kan de kalla väggpartierna lätt kartläggas och eventuell luftströmning konstateras medelst anemometer. På motsvarande sätt erhålls vid övertryck i den undersökta byggnaden uppvärmda väggpartier på väggens varma sida där rumsluft strömmar ut.

3.3 IR-kamerans upplösningsförmåga vid termografering av byggnader

IR-kamerans temperaturupplösningsförmåga i närheten av rumstemperatur är högst $0,2^{\circ}\text{C}$. Med kännedom om denna uppgift kan man bestämma den minsta reducering av en väggs värmemotstånd som IR-kameran nätt och jämnt kan upptäcka vid olika yttre betingelser.

Exempel

En yttervägg bestående i huvudsak av 15 cm mineralull med värmeledningsförmågan $0,03 \text{ W/m}^{\circ}\text{C}$ testas. Ur detta fås väggens värmemotstånd, $m = 0,15/0,03 \text{ m}^2,^{\circ}\text{C/W}$.

Värmeövergångskoefficienten α_{ute} väljes till $20 \text{ W/m}^2,^{\circ}\text{C}$ och α_{inne} till $6 \text{ W/m}^2,^{\circ}\text{C}$. Med hjälp av ekv. (15) och (18) fås för lufttemperaturskillnaden 10°C att en minskning av väggisoleringen med 40 % nätt och jämnt kan upptäckas. Motsvarande isoleringsminskning för lufttemperaturskillnaden 20°C är 25 % och för temperaturskillnaden 40°C 14 %.

Av exemplet framgår, att en viss minimitemperaturskillnad mellan rums- och ytterluft vid termografering alltid måste förutsättas för uppnående av erforderlig upplösningsförmåga. Sambandet mellan tillgänglig temperaturgradient över väggen och lägsta upptäckbara isoleringsminskning framgår av FIG. 13.

Vid termografering av otäthetsfel är förhållandena gynnsammare. Detta gäller särskilt vid undertryck i rummet. Eftersom i detta fall ytterluften kommer i direkt kontakt med väggens varma yta och kyler denna är det tillfyllest med endast någon grads temperaturskillnad mellan rums- och ytterluft för att en tydlig indikation i form av lägre ytemperatur skall kunna erhållas.

3.4 Förslag till tolkningsregler

Som tidigare angivits (se 3.1) måste ytemperaturmätningens (termograferingens) uppgift begränsas till att lokalisera brister i ytterväggars värmeisolering och eventuellt bestämma bristernas art. Man kan även formulera mätuppgiften så att ytemperaturmätningen avser att konstatera om den undersökta väggen besitter utlovade värmeisoleringsegenskaper utan att därför kvantitativt bestämma väggens värmemotstånd. De »utlovade värmeisoleringsegenskaperna» för väggen enligt ritning kan nämligen omsättas i en förväntad ytemperaturfördelning för den undersökta ytan om mätbetingelser vid måttillfället är kända.

Vid fältmätning förfares på följande sätt:

Den förväntade ytemperaturfördelningen jämförs med termogram av den undersökta väggen. Konstateras avvikelser som ej kan förklaras av konstruk-

3.3 Resolution capacity of the IR-camera during thermography of buildings

The temperature resolution capacity of the IR-camera near room temperature is a maximum of 0.2°C . On the basis of this information, it is possible to determine the least reduction in the thermal resistance of a wall which the IR-camera will just detect during different external conditions.

Example

An external wall consisting mainly of 15 cm mineral wool with a thermal conductivity of $0.03 \text{ W/m}^{\circ}\text{C}$ is being tested. From that the thermal resistance of the wall can be derived as $m = 0.15/0.03 \text{ m}^2,^{\circ}\text{C/W}$.

The surface coefficient of heat transfer α_{ext} is put at $20 \text{ W/m}^2,^{\circ}\text{C}$ and α_{int} at $6 \text{ W/m}^2,^{\circ}\text{C}$. It is found with the aid of Equations (15) and (18) that a reduction in wall insulation of 40 % can just be detected for a difference in air temperature of 10°C . Corresponding reductions in insulation are 25 % for a difference in air temperature of 20°C and 14 % for a difference in air temperature of 40°C .

It will be evident from the example that there must always be a certain minimum difference in temperature between the air in the room and that outside in order that the required resolution capacity may be attained during thermography. The relation between the available temperature gradient across the wall and the lowest detectable reduction in insulation is shown in FIG. 13.

During thermography of leakage defects, conditions are more favourable, particularly if the pressure in the room is lower than that outside. Since in this case external air comes into direct contact with the warm surface of the wall and cools this down, a difference in temperature of a degree or two between the air in the room and that outside is sufficient for a clear indication in the form of a lower surface temperature to be obtained.

Isoleringsminskning, som nätt och jämnt kan upptäckas, i % av väggens ursprungliga tjocklek
Reduction in insulation which can just be detected as a percentage of the original thickness of the wall.

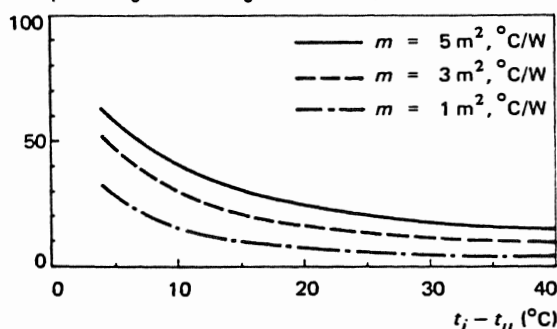


FIG. 13. Samband mellan minsta upptäckbara isoleringsreduktion och tillgängligt temperaturfall genom vägg ($\alpha_{\text{ute}} = 1/m_u = 20 \text{ W/m}^2,^{\circ}\text{C}$, $\alpha_{\text{inne}} = 1/m_i = 6 \text{ W/m}^2,^{\circ}\text{C}$). Väggs värmemotstånd utgör parameter.

Relation between the lowest detectable reduction in insulation and the available temperature drop across the wall ($\alpha_u = 1/m_u = 20 \text{ W/m}^2,^{\circ}\text{C}$, $\alpha_i = 1/m_i = 6 \text{ W/m}^2,^{\circ}\text{C}$). The parameter is the thermal resistance of the wall.

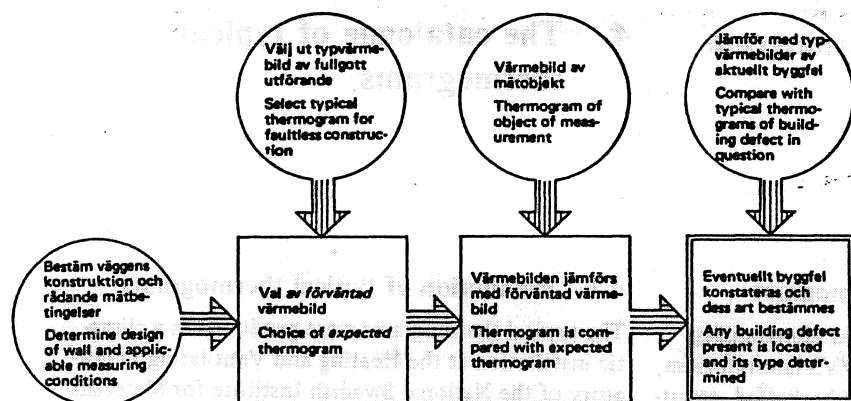


FIG. 14. Schema för tolkning av värmebilder (termogram).

Diagram for interpretation of thermograms.

tionsritning eller mätbetingelser, noteras dessa som misstänkta byggfel. Därefter fastställs möjlig typ av byggfel.

Följande hjälpmedel erfordras för genomförande av den ovan skisserade proceduren:

1. En metod för bestämning av förväntad temperaturfördelning för angiven väggkonstruktion vid de mätbetingelser som råder vid mättillfället.
2. En metod för typbestämning av misstänkt byggfel med utgångspunkt från termogrammens utseende.

Den metod som skulle ligga närmast till hands för framtagning av förväntade temperaturfördelningar är en analytisk bestämning med hjälp av dator eller elektriska analogier. Denna metod blir dock alltför omständlig och kostsam vid rutinundersökning av byggnader. Det synes därför vara ändamålsenligare att i stället tillämpa följande förfarande. Med hjälp av laboratorieförsök framställs i förväg en förväntad temperaturfördelning, i form av »typtermodrogram», för vanligen förekommande väggkonstruktioner vid vissa typiska klimatbetingelser. De så erhållna typtermodrogrammen samlas i ett typerregister och används sedan som jämförelsemall. Vid praktiskt bruk utväljer man ett typtermodrogram ur registret med utgångspunkt från aktuell väggkonstruktion och vid fältmätningen rådande betingelser. Byggfelens art bedöms på analogt sätt genom jämförelse med typtermodrogram för typiska och vanligen förekommande byggfel. Proceduren för tolkning av termogram framgår i princip av blockdiagrammet i FIG. 14.

3.4 Proposed rules of interpretation

As stated earlier (see 3.1), use of the measurement of surface temperature (thermography) must be confined to *location* of defects in the thermal insulation of external walls and possibly to determination of the type of defect. The use of the process may also be defined by saying that *the object of surface temperature measurement is to ascertain whether or not the wall being examined possesses the specified heat insulation properties, without determining at the same time the thermal resistance of the wall quantitatively*. This is possible since the »specified heat insulation properties» of the wall in accordance with the drawings can be converted into an expected surface temperature distribution for the surface being examined, if the measuring conditions at the time of measurement are known.

The procedure during field measurements is as follows:

The expected surface temperature distribution is compared with the thermogram of the wall examined. If deviations are found which cannot be explained by the design drawings or measuring conditions, these are noted as suspected building defects. The likely type of building defect is then established.

The following aids are required in order that the procedure outlined above may be carried out:

1. A method for determination of the expected temperature distribution for the specified wall construction for the measuring conditions which obtain at the time of measurement.
2. A method for determination of the type of suspected building defect on the basis of the appearance of the thermogram.

The most obvious method for the determination of the expected temperature distributions is an analytical procedure using a computer or electrical analogies. This method is however far too lengthy and costly to be used for routine examinations of buildings, and it would therefore appear more appropriate to apply the following procedure instead. On the basis of tests in the laboratory, an expected temperature distribution is drawn up in advance in the form of a typical thermogram for common wall constructions for certain typical climatic conditions. The typical thermograms so obtained are collected in a catalogue and are then used as the standards of comparison. In practice, a typical thermogram is selected from the catalogue on the basis of the wall construction in question and the conditions applicable to the time field measurements are carried out. The type of building defect is assessed in a similar way by comparison with typical thermograms for typical building defects which are of usual occurrence. The procedure for interpretation of thermograms is shown in principle in the block diagram in FIG. 14.

4 Register med typtermogram

4.1 Framställning av typtermogram

Typtermogrammen framställdes i en klimatanläggning på Statens provningsanstalts VVS-laboratorium, FIG. 15. Klimatanläggningen var så beskaffad att utomhus- respektive inomhusförhållanden kunde skapas på båda sidor av en provvägg, se FIG. 16. Provväggen uppbyggdes så att ett hörnparti motsvarande ytterväggshörn med del av innertak och ovanpå liggande yttertak bildades. Väggen var försedd med ett dubbelglasfönster. Genom denna provväggsform kunde en stor del av i praktiken förekommande, för byggfel utsatta, väggpartier intäckas.

4.1.1 Felfria provväggar

De valda provväggstyperna framgår av TAB. 1 och konstruktionsritningar FIG. 17, 18, 19 och 20. Provväggarnas inre värmeövergångskoefficient och emissionstal för innerytan anges även i figurerna. De »felfria» provväggarna uppbyggdes av yrkesmän. Avsikten var att konstruktionerna skulle få en medelgod i praktiken förekommande standard utan utförandefel. Termografering utfördes av provväggens varma yta för olika standardtemperaturer på den kalla sidan och vid stationärt tillstånd.

Strålningsförhållanden: Provrums värme källa var placerad i en vägg parallell med provväggen och utgjordes av en elradiator försedd med strålningsskydd av blank aluminium. Rummets begränsningsytor utom provväggen hade yttemperaturen ca 21°C.

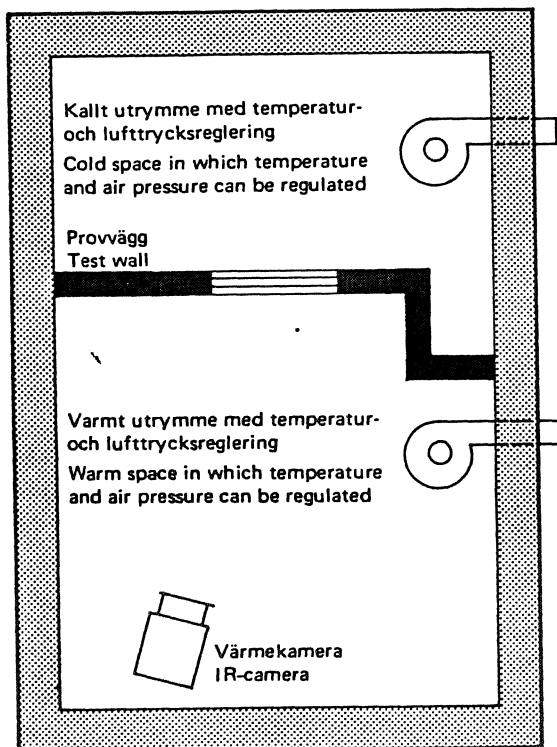


FIG. 15. Principskiss av klimatanläggning för framställning av typ-termogram.

Sketch showing arrangement of climatic installation for production of typical thermograms.

FIG. 16. Fotografi av provvägg.

Photograph of test wall.

4 The catalogue of typical thermograms

4.1 Production of typical thermograms

The typical thermograms were produced in a climatic installation at the Heating and Ventilating Laboratory of the National Swedish Institute for Materials Testing, FIG. 15. The climatic installation was such that indoor and outdoor conditions could be simulated on both sides of a test wall, see FIG. 16. The test wall was constructed in such a way that it formed a corner corresponding to the corner of an external wall with part of the ceiling and the roof above this. The wall was fitted with a double-glazed window. By using this form of test wall, it was possible to cover a large proportion of wall types subject to building defects which occur in practice.

4.1.1 Test walls with no defects

The selected types of test walls are shown in TAB. 1 and the design drawings in FIGs. 17, 18, 19 and 20. The internal thermal transmittance and the emissivity of the internal surface is also given in the Figures. The test walls »without defects» were constructed by craftsmen, the intention being that the construction should comply with a medium standard without defects in workmanship which can be met with in practice. Thermography was carried out on the warm side of the test wall for different standard temperatures on the cold side and in the steady state.

Radiation conditions: The source of heat in the test room was placed in a wall parallel to the test wall



TAB. 1. Undersökta väggkonstruktioner.

Regelvägg nr 1

Yttervägg med 110 mm mineralullsisolering, se FIG. 17. Den felfria väggen exponerades för klimat nr 1–12 enligt TAB. 2. Motsvarande vägg med inbyggda (avsiktliga) fel exponerades för klimat 1–11 enligt TAB. 2.

Regelvägg nr 2

Yttervägg med 100 mm mineralullsisolering och 30 mm tilläggsisolering av karbamidcellplast, se FIG. 18. Den felfria väggen exponerades för klimat nr 4, 5 och 6 enligt TAB. 2. Motsvarande vägg med inbyggda (avsiktliga) fel exponerades för klimat 4, 5 och 6 enligt TAB. 2.

Sandwichvägg

Yttervägg med 80 mm polystyrenisolering mellan skivor av betong, se FIG. 19. Den felfria väggen exponerades för klimat nr 1, 4 och 8 enligt TAB. 2. Motsvarande vägg med inbyggda (avsiktliga) fel exponerades för klimat nr 1–6 och 8, 9, 10 enligt TAB. 2.

Lättbetongvägg

Yttervägg av 250 mm lättbetongblock, skrymdensitet 500 kg/m^3 , se FIG. 20. Den felfria väggen exponerades för klimat nr 1, 4 och 8 enligt TAB. 2. Motsvarande vägg med inbyggda (avsiktliga) fel exponerades för klimat nr 1–6 och 8–10 enligt TAB. 2.

Luftströmningsförhållanden: I de fall övertryck eller undertryck skapades på provväggens varma sida var provrummet anslutet till inblåsnings- resp. utsugningsfläkt. Luftstrålen från inblåsningsfläkten riktades med hjälp av en skärm mot rummets mitt. Värmeövergångskoefficienten vid provväggarnas varma yta uppmättes i vissa punkter och anges i FIG. 17, 18, 19 och 20. På provväggens kalla sida infördes ingen påtvingad konvektion eftersom resulterande ändring av övergångsmotståndet utgör en ringa del av väggens totala värmemotstånd och ej nämnvärt påverkar yttemperaturen på den varma sidan.

För varje provvägg valdes tre utomhustemperaturer: -20°C , -5°C och $+10^\circ\text{C}$ och för varje utomhustemperatur i huvudsak tre tryck i provrummet, $+50$, ± 0 och -50 N/m^2 för åstadkommande av luftläckage. Lufttemperaturen i provrummet var konstant $+21^\circ\text{C}$ vid samtliga mätningar. Dessutom utfördes en mätning med påkopplad elradiator placerad under provväggens fönster. Provrumsdimensionerna medförde att provväggsytan måste uppdelas i fyra bildfält i enlighet med FIG. 21.

Termograferingsarbetet utfördes med IR-kamera av typ AGA Thermovision Modell 665 med bildvinkel $20 \times 20^\circ$. Som jämförelse utfördes även termografering av provvägg nr 4 med en IR-kamera av typ Bofors »IR-Camera», se BIL. 55 och 56.

Gråtonsskalan inreglerades vid mätningarna så att god balans mellan ljusare och mörkare partier erhöles. Samtliga mätfall anges i TAB. 2.

4.12 Provväggar med inbyggda fel

Typtermogram av provväggar med inbyggda fel framställdes på analogt sätt. I de fyra provväggarna utfördes ett antal byggfel av vanligen förekommande typer. De införda byggfelen anges i detalj på FIG. 22, 23, 24 och 25 i form av ritningar, fotografier och be-

TAB. 1. Wall structures studied.

Framed cladding panel No. 1

External wall with 110 mm mineral wool insulation, see FIG. 17. The wall without faults was exposed to climatic conditions Nos. 1–12 according to TAB. 2. The corresponding wall with deliberate faults was exposed to climatic conditions Nos. 1–11 according to TAB. 2.

Framed cladding panel No. 2

External wall with 100 mm mineral wool insulation and 30 mm additional insulation of expanded polyurethane, see FIG. 18. The wall without faults was exposed to climatic conditions Nos. 4, 5 and 6 according to TAB. 2. The corresponding wall with deliberate faults was exposed to climatic conditions Nos. 4, 5 and 6 according to TAB. 2.

Sandwich wall

External wall with 80 mm polystyrene insulation between slabs of concrete, see FIG. 19. The wall without faults was exposed to climatic conditions Nos. 1, 4 and 8 according to TAB. 2. The corresponding wall with deliberate faults was exposed to climatic conditions Nos. 1–6, 8, 9 and 10 according to TAB. 2.

Light concrete wall

External wall of 250 mm light-weight concrete blocks, bulk density 500 kg/m^3 , see FIG. 20. The wall without faults was exposed to climatic conditions Nos. 1, 4 and 8 according to TAB. 2. The corresponding wall with deliberate faults was exposed to climatic conditions Nos. 1–6 and 8–10 according to TAB. 2.

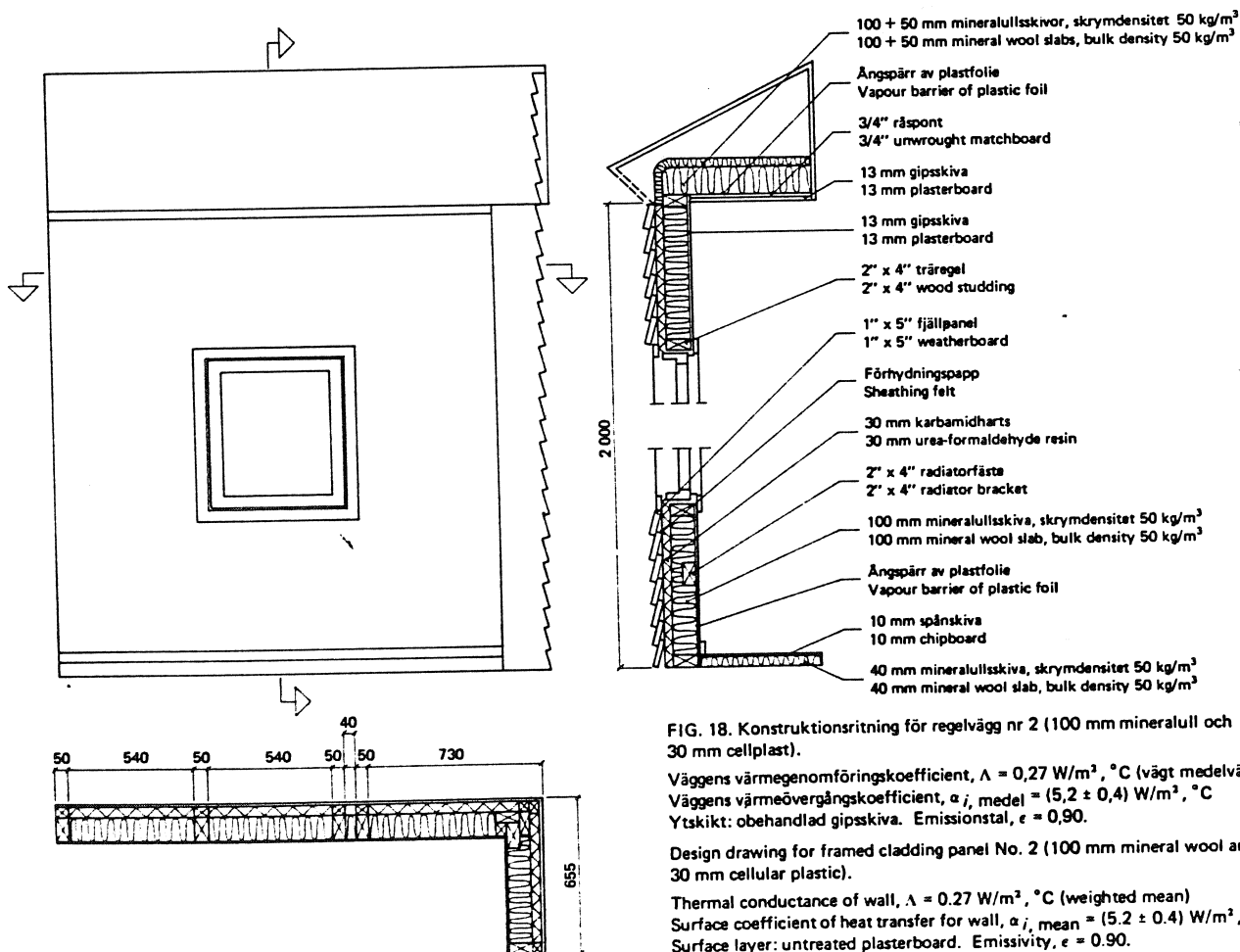
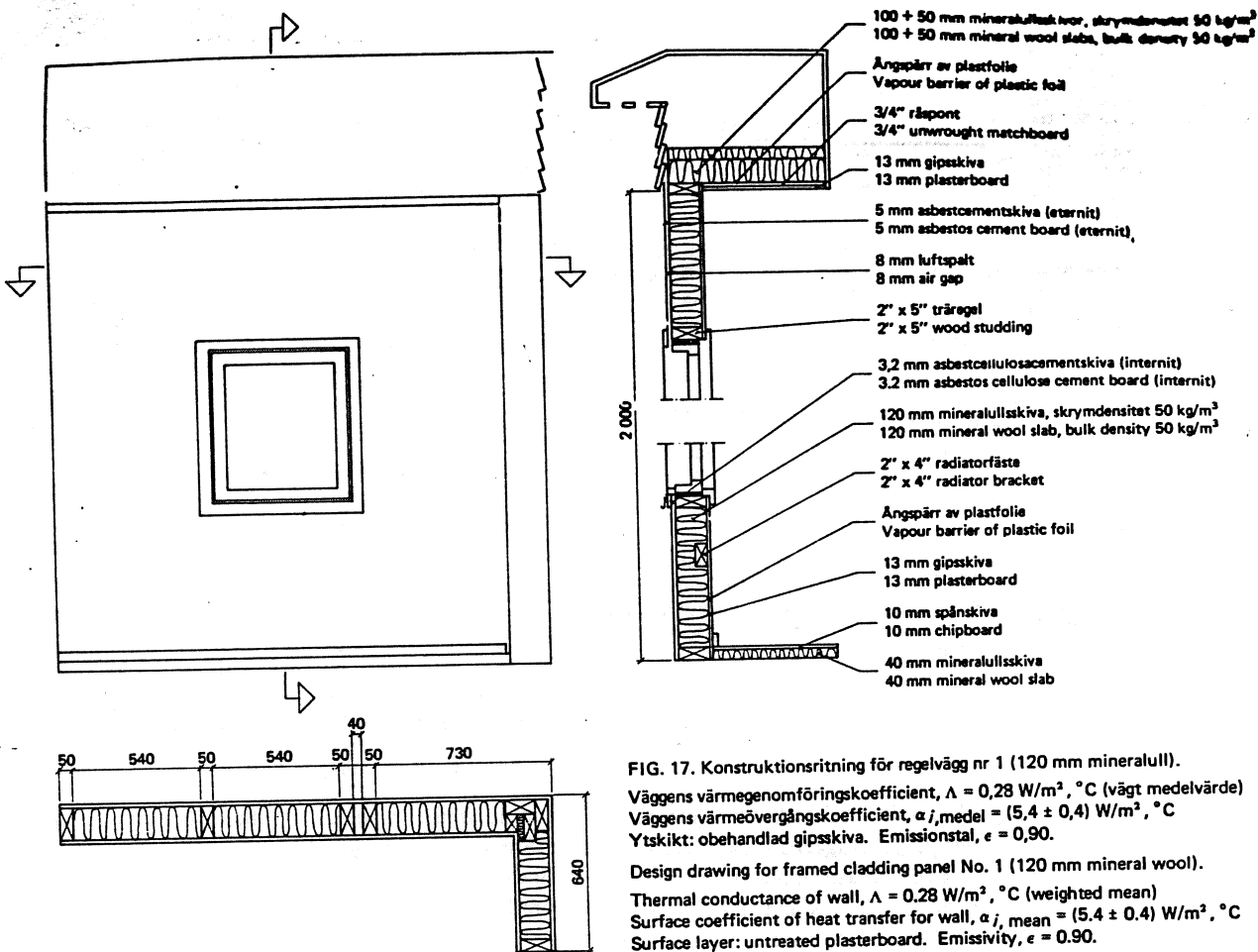
and consisted of an electric radiator fitted with a radiation screen of bright aluminium. With the exception of the test wall, the boundary walls of the test room had a surface temperature of about 21°C .

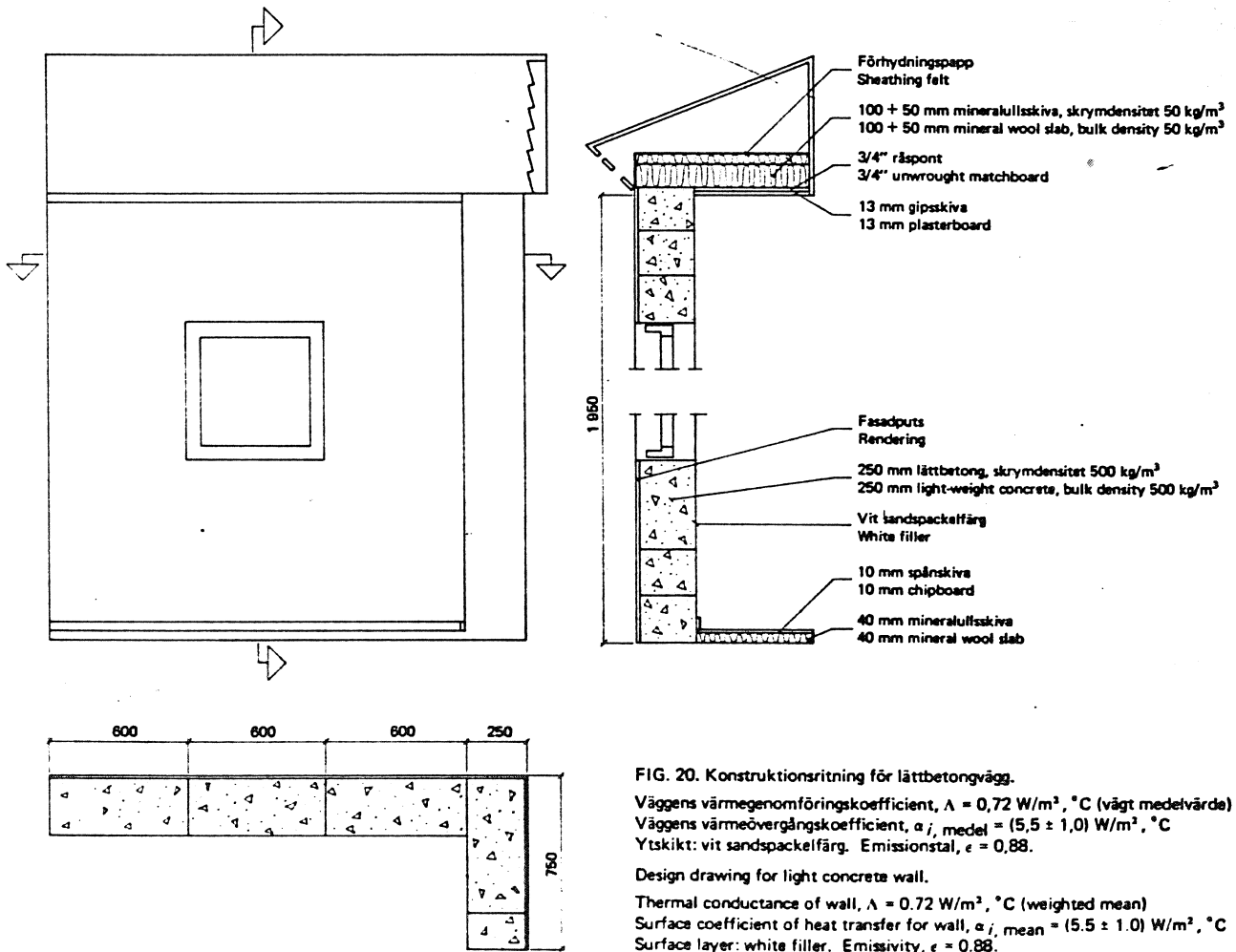
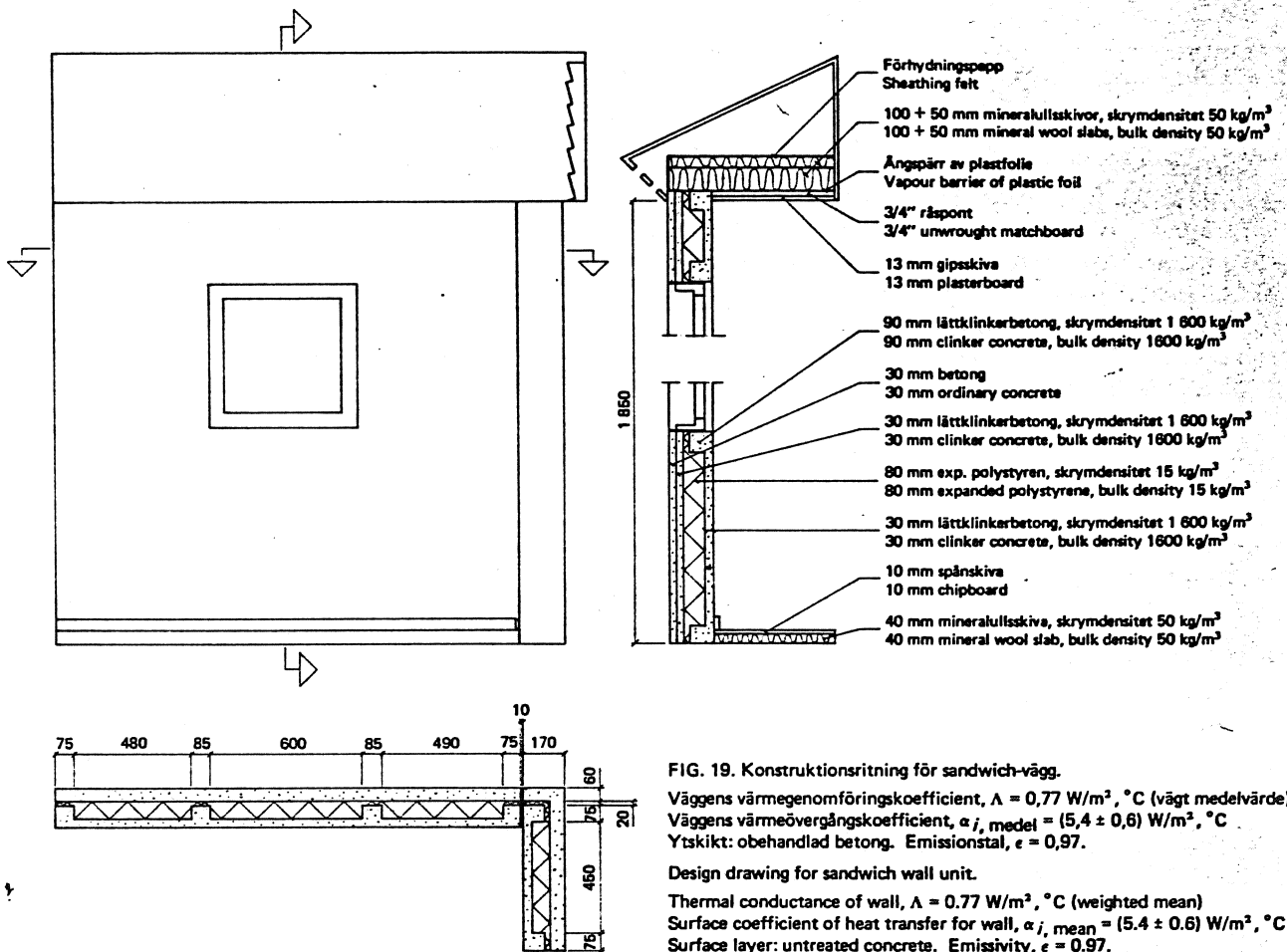
Air flow conditions: In cases when the warm side of the test wall was put at a higher or lower pressure than the cold side, the test room was connected to a blower or extraction fan respectively. With the aid of a screen, the air jet from the blower was directed towards the centre of the room. The surface coefficient of heat transfer on the warm surface of the test walls was measured at certain points and is shown in FIGs. 17, 18, 19 and 20. No forced convection was imposed on the cold side of the test wall, since the resulting change in the surface resistance constitutes only a slight proportion of the total thermal resistance of the wall and has no appreciable influence on the surface temperature on the warm side.

Three outdoor temperatures, -20°C , -5°C and $+10^\circ\text{C}$, were chosen for each test wall and in principle three pressures, $+50$, ± 0 and -50 N/m^2 , in the test room for each of these outdoor temperatures in order to cause leakage of air. During all measurements, the air temperature in the test room was constant at $+21^\circ\text{C}$. A measurement was carried out in addition with a switched-on electric radiator placed below the window in the test wall. As shown in FIG. 21, the dimensions of the test room were such that the surface of the test wall had to be divided into four frames.

Thermography was carried out by means of an IR-camera AGA Thermovision Model 665 with a view angle of $20 \times 20^\circ$. Thermography of test wall No 4 was also carried out by means of a Bofors IR-camera in order to provide a comparison, see Appendices 55 and 56.

The grey scale was adjusted during measurements so that satisfactory balance was obtained between light





TAB. 2. Provklimat / Climatic conditions for testing purposes.

Inomhustemperaturen, t_i , har varit +21°C vid samtliga mätningar. Utomhustemperaturen, t_u , temperaturskillnaden, Δt , tryckskillnaden, Δp , över provväggen samt lufttemperaturen i provväggens vindsutrymme, t_{vind} anges nedan.

The indoor temperature (t_i) was +21°C during all measurements. The outdoor temperature (t_u), the temperature difference (Δt), the pressure difference (Δp) across the test wall and the air temperature (t_{attic}) in the attic space of the test wall, are tabulated below.

Klimat nr / Climatic condition No	t_u °C	Δt °C	Δp N/m ²	$t_{vind} /$ t_{attic} °C
1	+10	11	0	+11
2 ¹	+10	11	+50	+11
3 ²	+10	11	-50	+11
4	-5	26	0	-2
5	-5	26	+50	-2
6	-5	26	-50	-2
7	-5	26	-100	-2
8	-20	41	0	-15
9	-20	41	+50	-15
10	-20	41	-50	-15
11	-20	41	-100	-15
12 ³	-20	41	0	-15

¹Övertryck på varma sidan / Pressure higher on warm side

²Undertryck på varma sidan / Pressure lower on warm side

³Uppvärmningsradiator påkopplad / Radiator switched on.

skrivande text. Samtliga mätfall för väggar försedda med fel anges i TAB. 1.

I BIL. 1–54 visas typbilder av väggar, såväl felfria som försedda med inbyggda fel. Varje bilaga omfattar ett mätfall och sammansätts av provväggens fyra bildfält. För vart och ett av bildfälten presenteras dels en gråtonsbild, dels två isothermbilder. På isothermbilderna anges temperaturskillnaden mellan två isotermer i °C. För vissa mätfall har även medtagits ett färgtermogram. På varje bilaga anges: Väggtyp, klimatfall, »felfri» eller »felförsedd». Bilderna är betecknade med bokstav (A, B, C, D) som anger bildfält på provväggen och siffror som anger bildtyp: 1. gråtonsbild, 2. isothermbild och 3. färgtermogram.

and dark portions of the image. All measuring conditions are described in TAB. 2.

4.12 Test walls with deliberate faults

Typical thermograms of test walls with artificial defects were produced in a similar way. A number of building defects of commonly occurring types were introduced into the four test walls. Details of these building defects are given in FIGs. 22, 23, 24 and 25 in the form of drawings, photographs and descriptive text. All particulars concerning walls with artificial defects are listed TAB. 1.

Appendices 1–54 show typical pictures of walls, both those without defects and those with artificial defects. Each appendix comprises one measuring occasion and is made up of the four frames relating to the test wall. One monochrome image and two isotherm images are presented for each frame. The difference in temperature between two isotherms is quoted in °C on the isotherm images. A colour thermogram has also been included for some measuring conditions. Each appendix contains information relating to type of wall, climatic condition, »without defect» or »with artificial defect». The pictures are denoted by letters (A, B, C, D) which indicate the frame on the test wall and a number which denotes the type of image: 1. monochrome image, 2. isotherm image and 3. colour thermogram.

FIG. 21. Provväggens indelning i bildfält, regelvägg nr 1.

Division of surface of test wall into frames, framed infill panel No. 1.

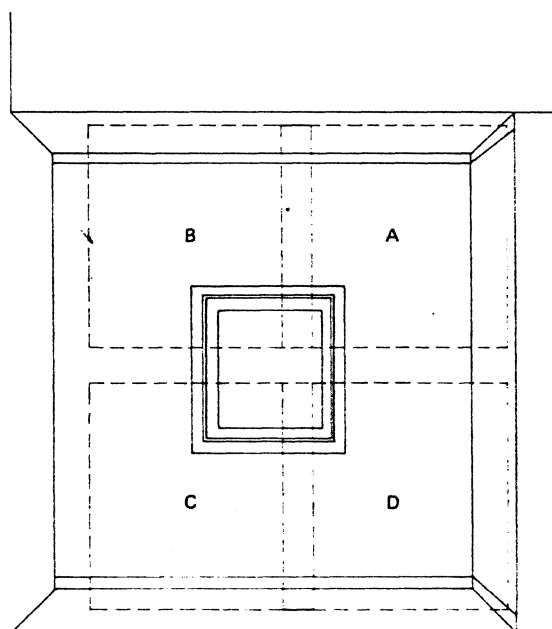
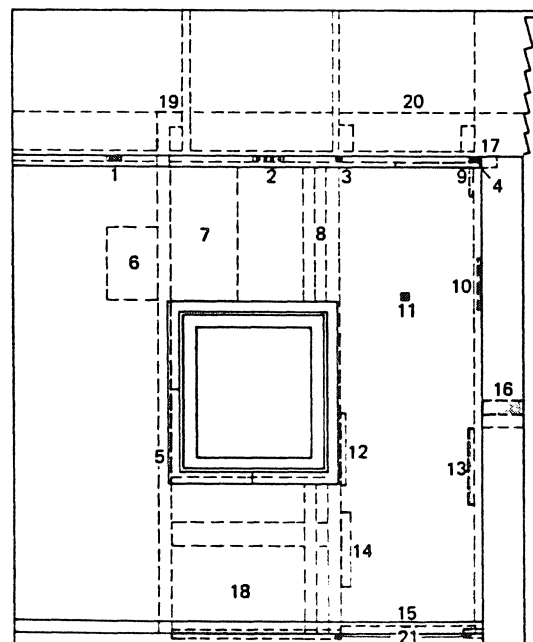


FIG. 22a. Regelvägg nr 1 (120 mm mineralull) med inbyggda fel. De avsiktliga byggfelen är markerade med siffror från 1–21.

Framed cladding panel No. 1 (120 mm mineral wool). The deliberate building defects are marked with numbers 1–21.

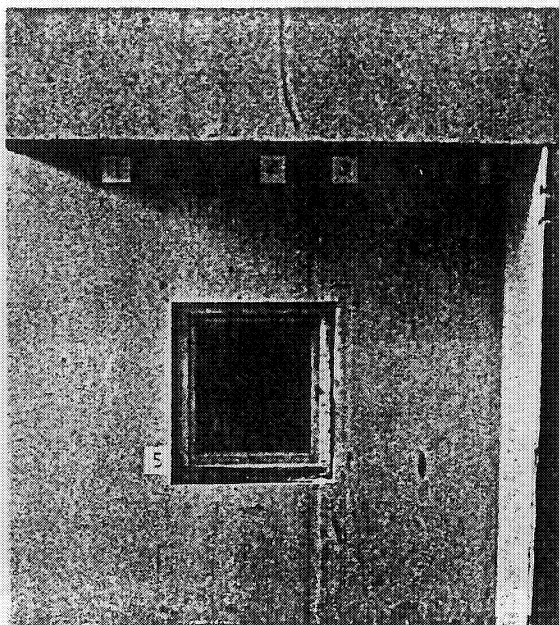


b. Fotografi av regelvägg nr 1 med fel nr 1–5 angivna.

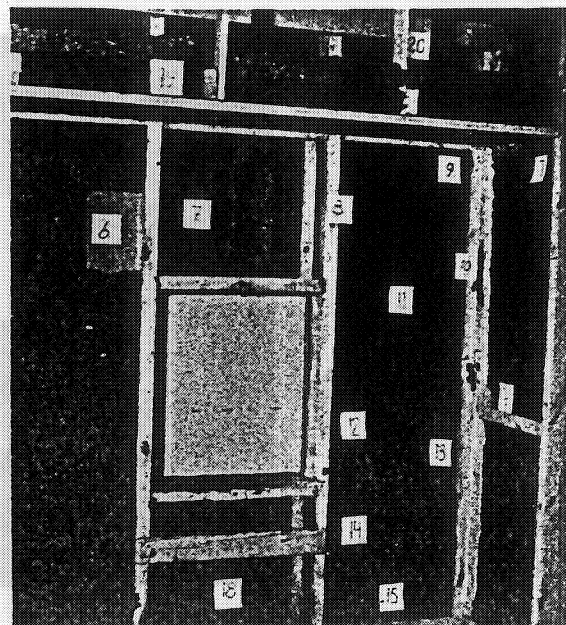
Photograph of framed cladding panel No. 1 with faults Nos. 1–5 shown.

c. Fotografi av regelvägg nr 1 med gipsplatta och plastfolie borttagna. Läget av fel nr 6–18 anges.

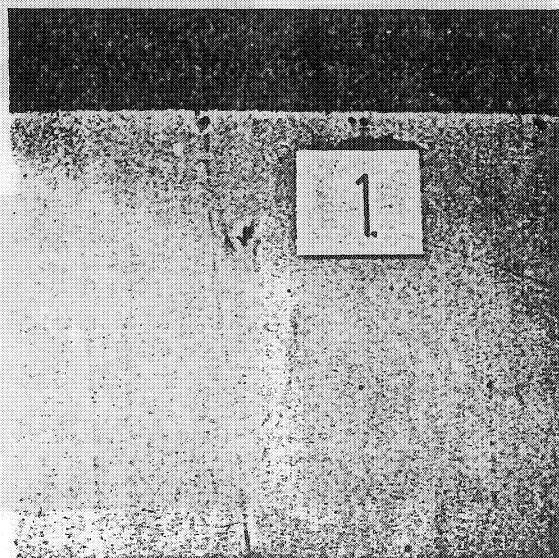
Photograph of framed cladding panel No. 1 with plasterboard and plastic foil removed. The positions of faults Nos. 6–18 are shown.



b



c



d

d. Fel nr 1. Två st hål med 4 mm diameter.

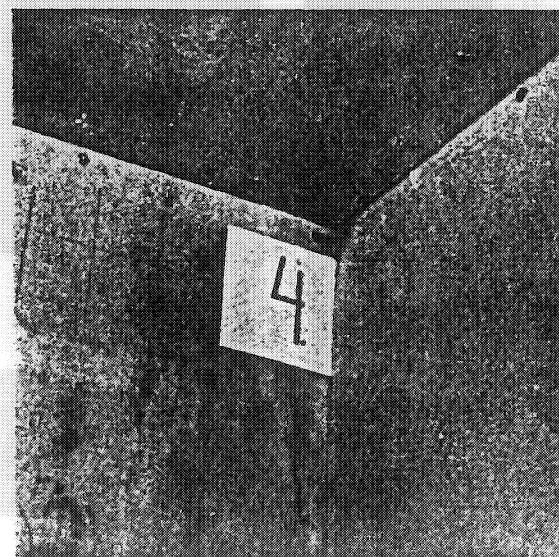
Fault No. 1. Two 4 mm dia. holes.



e

e. Fel nr 2 och 3. Fyra plus ett st hål med 4 mm diameter.

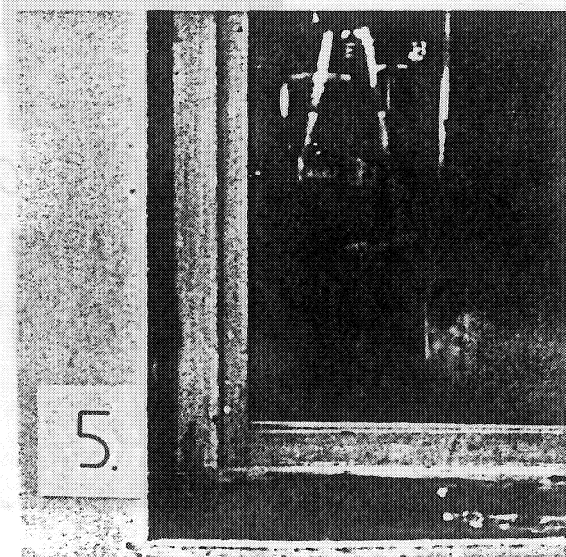
Fault Nos. 2 and 3. Four plus one 4 mm dia. holes.



f

f. Fel nr 4. Två st hål med 4 mm diameter.

Fault No. 4. Two 4 mm dia. holes.



g

g. Fel nr 5. Drevning vid fönsterkarm borttagen.

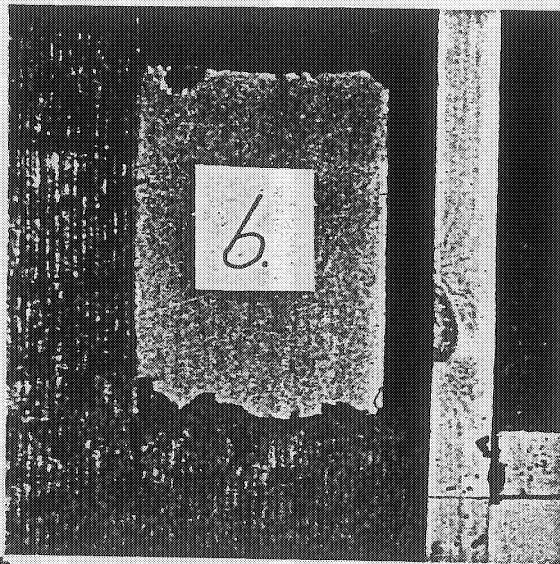
Fault No. 5. Weatherstrip at window frame removed.

h. Fel nr 6. Isolering helt borttagen.

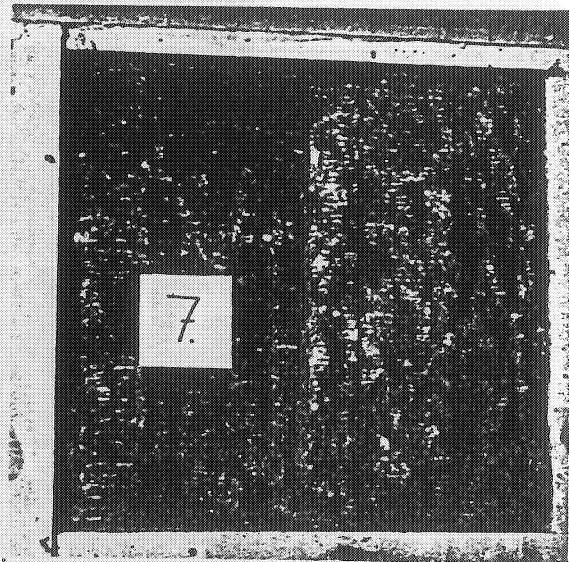
Fault No. 6. Insulation completely removed.

i. Fel nr 7. Sex cm isolering borttagen.

Fault No. 7. Six cm of insulation removed.



h



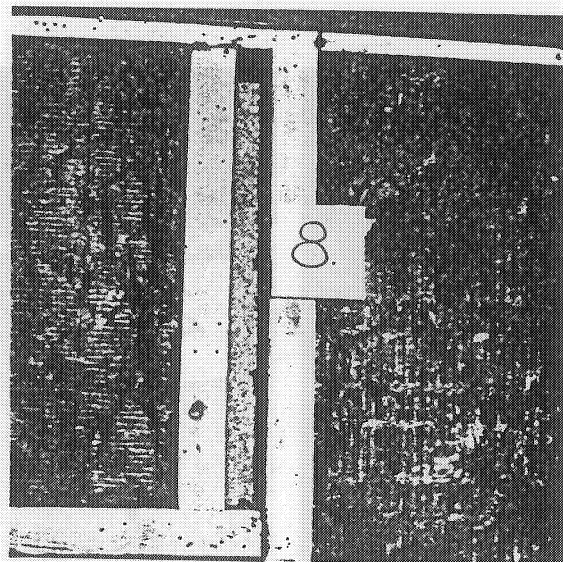
i

j. Fel nr 8. Isolering mellan reglar borttagen.

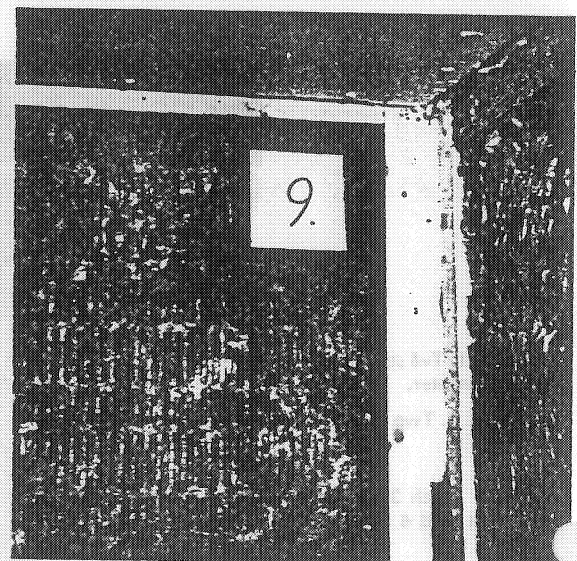
Fault No. 8. Insulation between studs removed.

k. Fel nr 9. Isolering ansluter ej mot regel vid hörn, spaltbredd 2 cm.

Fault No. 9. Insulation not in contact with stud at corner, gap width 2 cm.



j



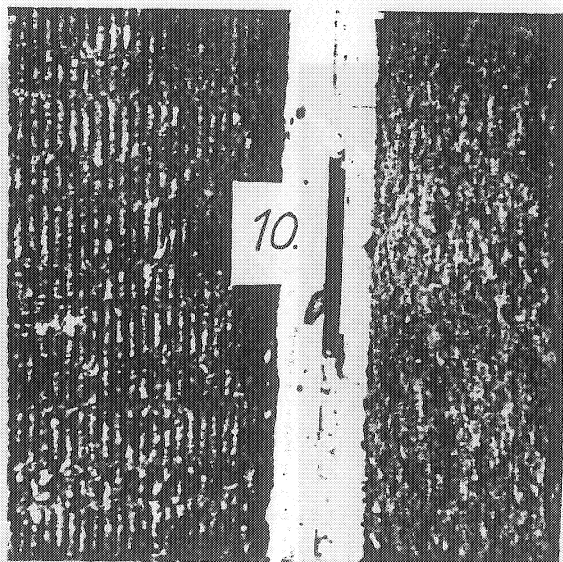
k

l. Fel nr 10. Drevning i hörn borttagen.

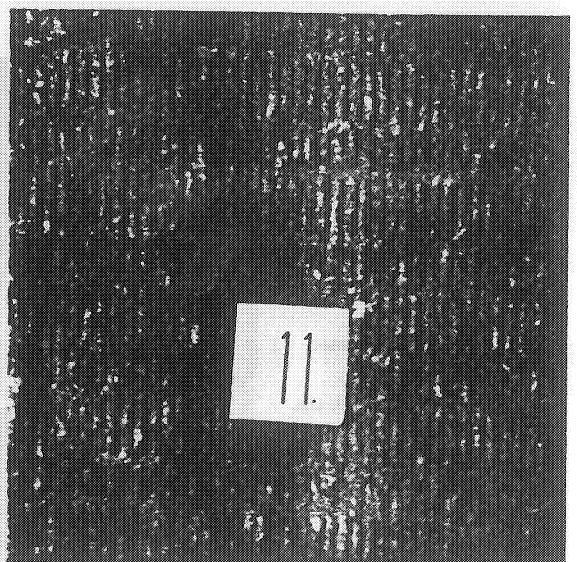
Fault No. 10. Weatherstrip at corner removed.

m. Fel nr 11. Hål i isolering 2 cm diameter.

Fault No. 11. Two cm dia. hole in insulation.



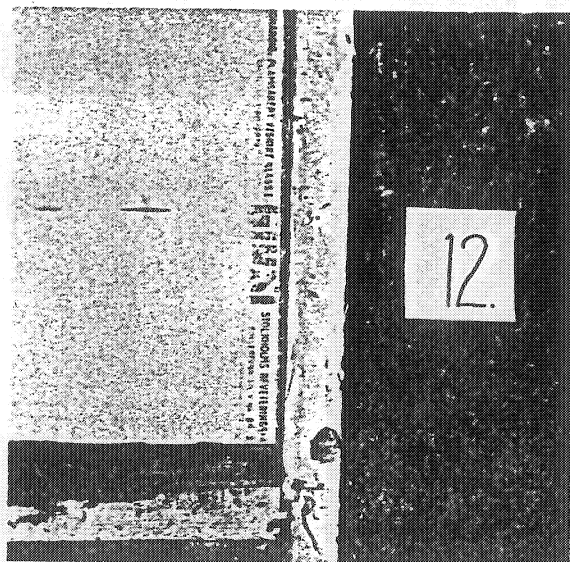
l



m

n. Fel nr 12. Isolering ansluter ej mot regel, spaltbredd 1,5 cm.

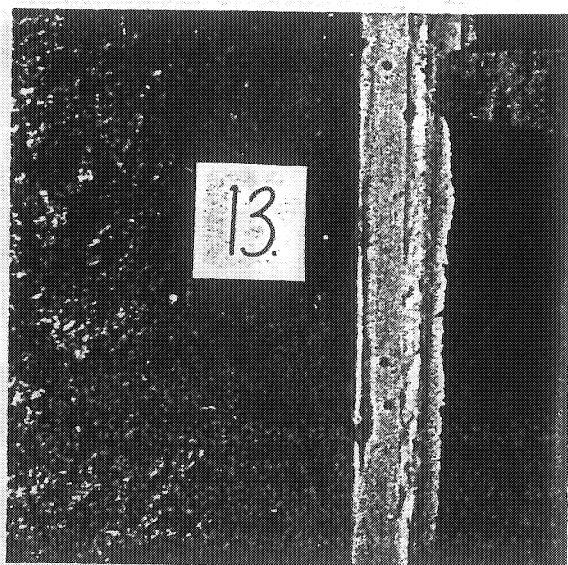
Fault No. 12. Insulation not in contact with stud, gap width 1.5 cm.



n

o. Fel nr 13. Isolering ansluter ej mot regel, spaltbredd 2 cm.

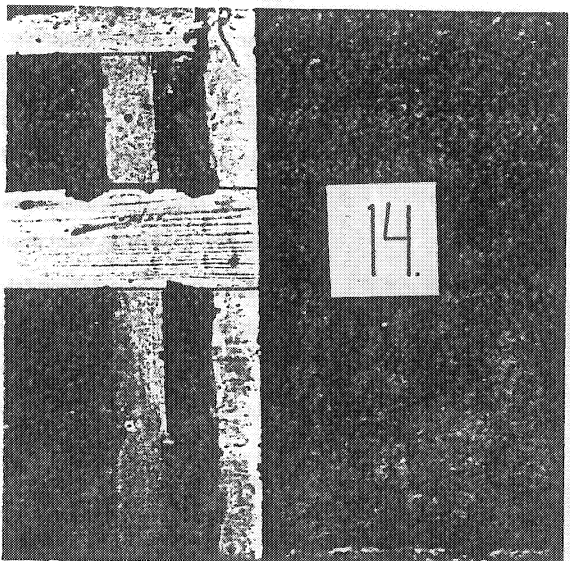
Fault No. 13. Insulation not in contact with stud, gap width 2 cm.



o

p. Fel nr 14. Isolering ansluter ej mot regel, spaltbredd 3 cm.

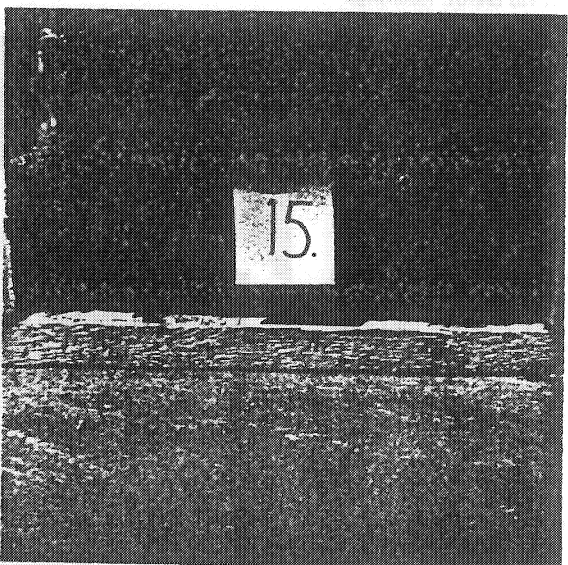
Fault No. 14. Insulation not in contact with stud, gap width 3 cm.



p

q. Fel nr 15. Isolering ansluter ej mot syll, spaltbredd 2 cm.

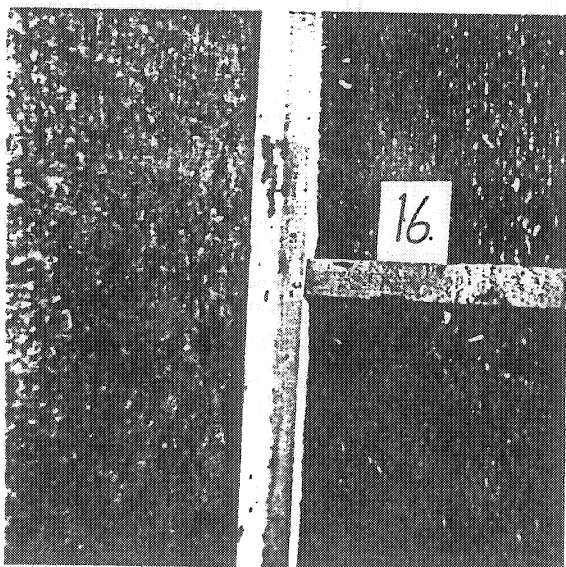
Fault No. 15. Insulation not in contact with bottom member, gap width 2 cm.



q

r. Fel nr 16. Hörn av isolering borttagen.

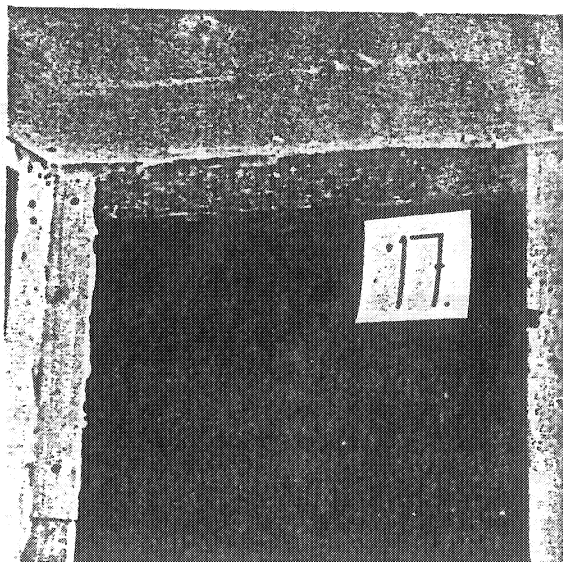
Fault No. 16. Corner of insulation removed.



r

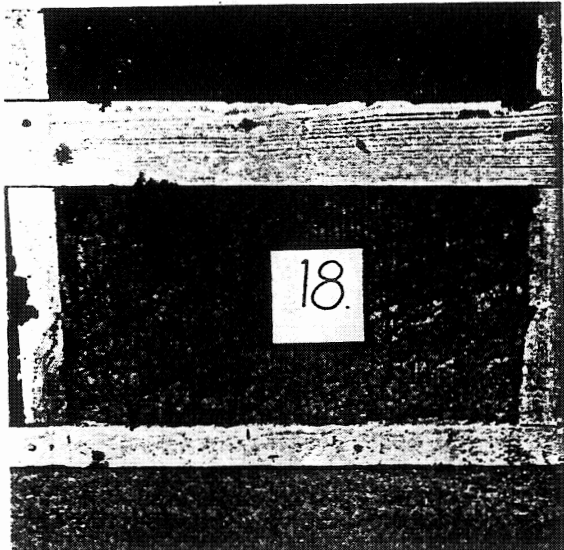
s. Fel nr 17. Isolering intryckt vid regel.

Fault No. 17. Insulation pushed back at stud.

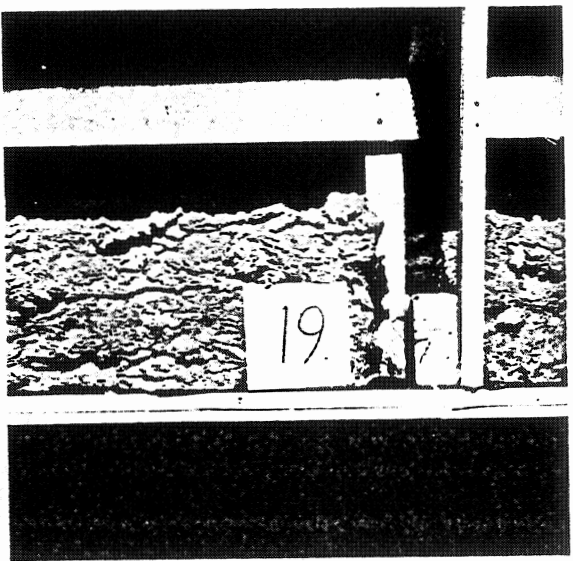


s

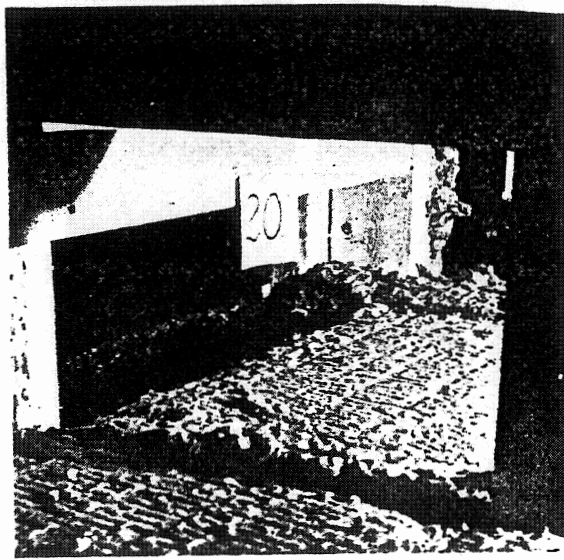
Fel nr 18. Fukt i isolering (vattenmättnad).
Fault No. 18. Moisture in insulation (saturation).



Fel nr 19. Isolering ansluter ej mot regel i tak, spaltbredd 4 cm.
Fault No. 19. Insulation not in contact with joist in ceiling, gap width 4 cm.



Fel nr 20. Isolering fyller ej ut vid takfot. Isoleringens bakre kant slutar 5 cm hitom väggens innersta.
Fault No. 20. Insulation not properly laid at the eaves. The rear edge of the insulation stops 5 cm short of the inside of the wall.



Fel nr 21. Tätningslist borttagen vid golvhörn och vid anslutning mellan provvägg och golvyta mitt under fönsterparti mellan de två vertikala reglarna som går på bänksidor om fönster. (Fotografi saknas).
Fault No. 21. Sealing strip removed at corner of floor and at the junction between test wall and floor right underneath the window between the two vertical studs on either side of the window (No photograph).

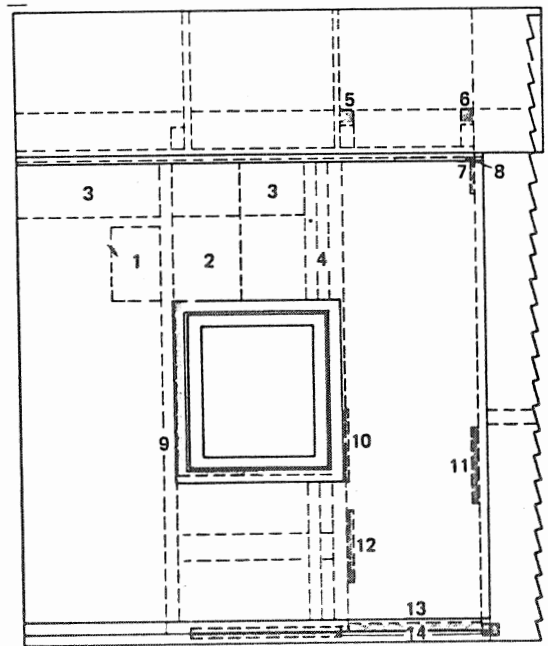


FIG. 23. Regelvägg nr 2 (100 mm mineralull och 30 mm cellplast) med inbyggda fel. De avsiktliga byggfelen har markerats med nummer som förklaras nedan.
Framed cladding panel No. 2 (100 mm mineral wool and 30 mm cellular plastic) with deliberate faults. These have been numbered as explained below.

- Fel nr 1. Mineralullsisolering helt borttagen.
Fault No. 1. Mineral wool insulation completely removed.
- Fel nr 2. Fem cm mineralullsisolering borttagen.
Fault No. 2. Five cm of mineral wool insulation removed.
- Fel nr 3. Tre cm karbamidharts borttagen.
Fault No. 3. Three cm of urea-formaldehyde resin removed.
- Fel nr 4. Mineralullsisolering mellan reglarna borttagen.
Fault No. 4. Mineral wool insulation removed between studs.
- Fel nr 5. Regel i tak frilagd från isolering.
Fault No. 5. Joist in ceiling has no insulation over it.
- Fel nr 6. Regel i tak frilagd från isolering.
Fault No. 6. Joist in ceiling has no insulation over it.
- Fel nr 7. Isolering ansluter ej mot regel vid hörn, spaltbredd 2 cm.
Fault No. 7. Insulation not in contact with stud at corner, gap width 2 cm.
- Fel nr 8. Två st hål med 4 mm diameter.
Fault No. 8. Two 4 mm dia. holes.
- Fel nr 9. Drevning och tätning vid fönsterkarm borttagen.
Fault No. 9. Weatherstrip and sealing strip at window frame removed.
- Fel nr 10. Isolering ansluter ej mot regel, spaltbredd 1,5 cm.
Fault No. 10. Insulation not in contact with stud, gap width 1.5 cm.
- Fel nr 11. Isolering ansluter ej mot regel i hörn, spaltbredd 2 cm.
Fault No. 11. Insulation not in contact with stud at corner, gap width 2 cm.
- Fel nr 12. Isolering ansluter ej mot regel, spaltbredd 3 cm.
Fault No. 12. Insulation not in contact with stud, gap width 3 cm.
- Fel nr 13. Isolering ansluter ej mot syll, spaltbredd 2 cm.
Fault No. 13. Insulation not in contact with bottom member, gap width 2 cm.
- Fel nr 14. Tätningslist borttagen.
Fault No. 14. Sealing strip removed.

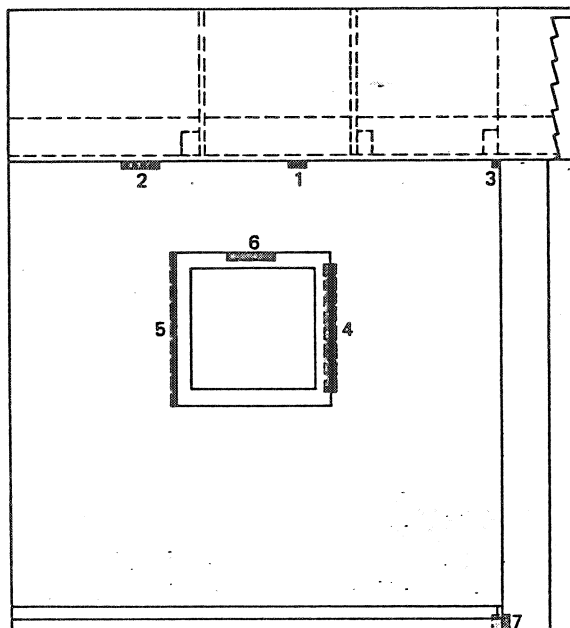
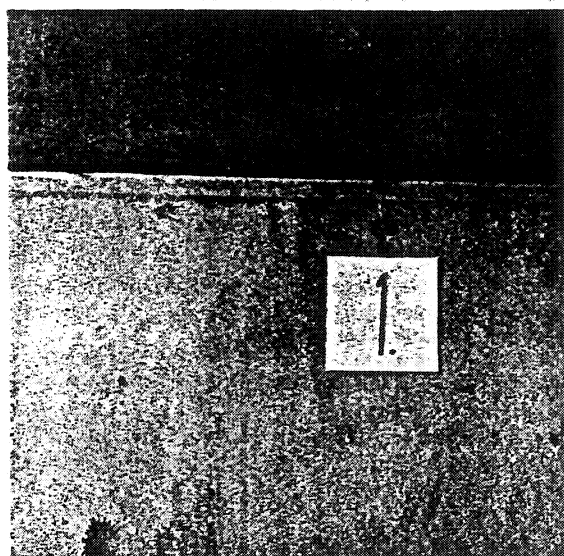


FIG. 24a. Sandwichvägg med inbyggda fel. De avsiktliga byggfelen har markerats med nummer som förklaras nedan.

Sandwich wall unit with deliberate faults. These have been numbered as explained below.

b. Fel nr 1. Två hål med 4 mm diameter.

Fault No. 1. Two 4 mm dia. holes.

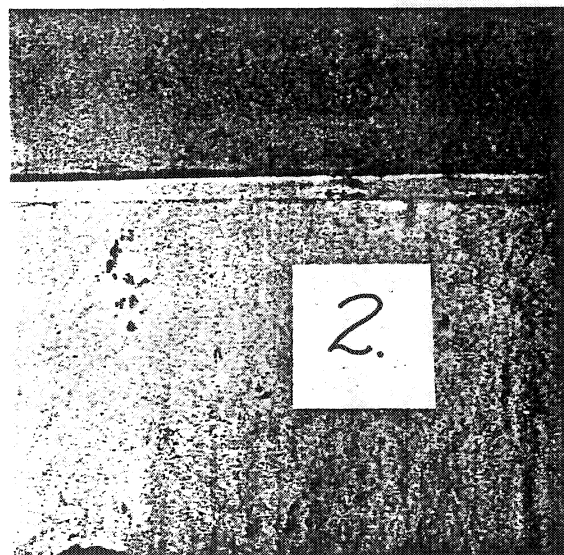


b

a

c. Fel nr 2. Fyra hål med 4 mm diameter.

Fault No. 2. Four 4 mm dia. holes.



c

d. Fel nr 3. Ett hål med 4 mm diameter.

Fault No. 3. One 4 mm dia. hole.



d

e. Fel nr 4. Fogmassa för tätning mellan fönsterkarm och vägg på insidan borttagen.

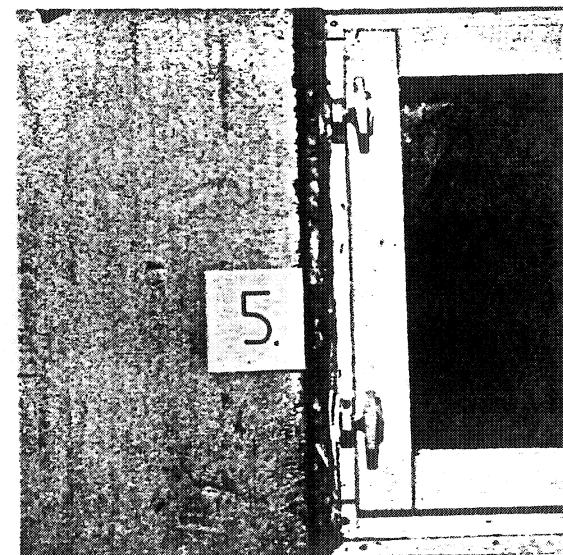
Fault No. 4. Sealing compound removed between window frame and wall on the inside.



e

f. Fel nr 5. Drevning mellan fönsterkarm och vägg borttagen.

Fault No. 5. Weatherstrip between window frame and wall removed.



f

g. Fel nr 6. Delar av tätningslist på fönsterbåge borttagna (foto saknas).

Fault No. 6. Parts of sealing strip on casement removed. (no photograph).

h. Fel nr 7. Yttre tätningslist vid fog i hörn borttagen (foto saknas).

Fault No. 7. Outer sealing strip at joint in corner removed (no photograph).

FIG. 25. Lättbetong-vägg med inbyggda fel. De avsiktliga byggfelen har markerats med nummer som förklaras nedan.

Light concrete wall with deliberate faults. These have been numbered as explained below.

Inbyggda fel / Faults incorporated in test walls

Nr 1. Regel i tak frilagd från isolering (foto saknas).

No. 1. No insulation over stud in ceiling (no photograph).

Nr 2. Isolering fyller ej ut vid takfot. Isoleringsskivans bakre kant slutar 5 cm hitom väggens inneryta. (foto saknas).

No. 2. Insulation not properly laid at the eaves. The rear edge of the insulation slab stops 5 cm short of the inside of the wall (no photograph).

Nr 3. Lättbetongstav till halva sin tjocklek borttagen. Djup 10 cm.

No. 3. Corner portion of light-weight concrete plank removed. Depth 10 cm.

Nr 4. Hörnbit av lättbetongstaven borttagen. Djup 10 cm.

Corner portion of light-weight concrete plank removed. Depth 10 cm.

Nr 5. Vindskyddet på takisoleringen borttaget. Vinkelrät påblåsning från utsidan arrangerades med en hastighet av 1 m/s.

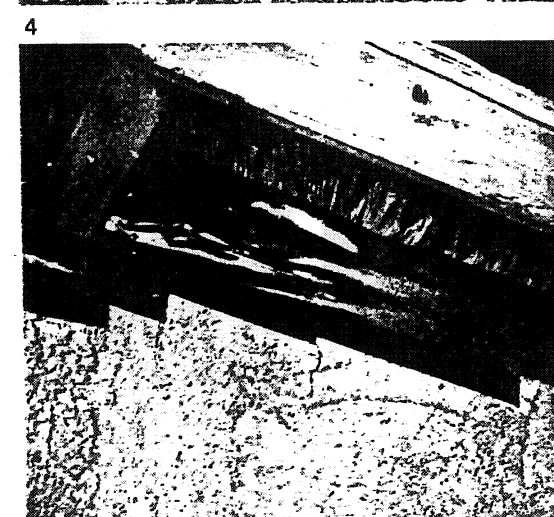
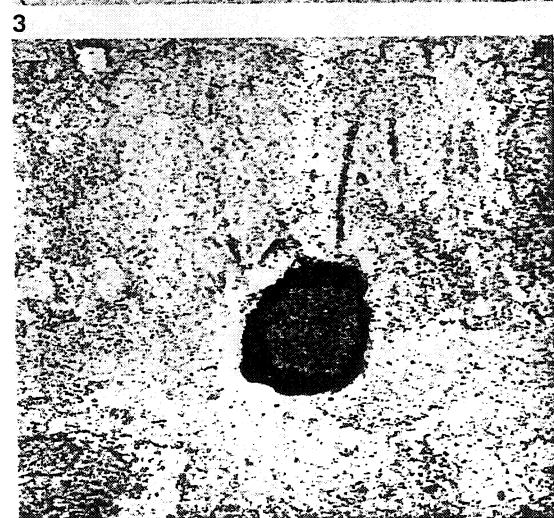
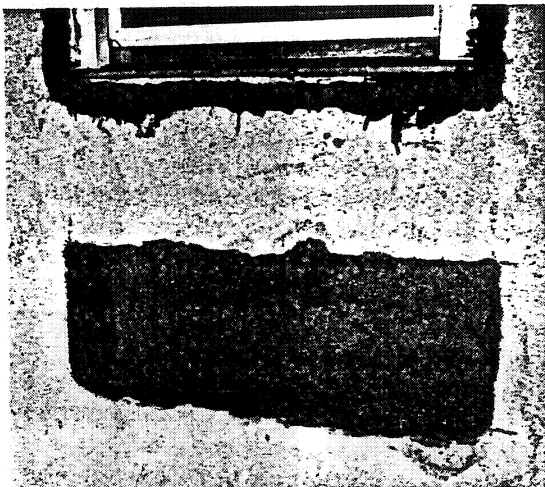
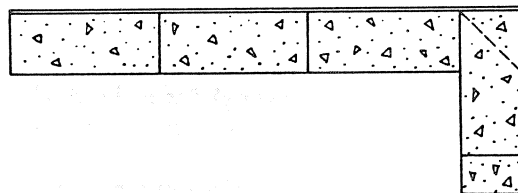
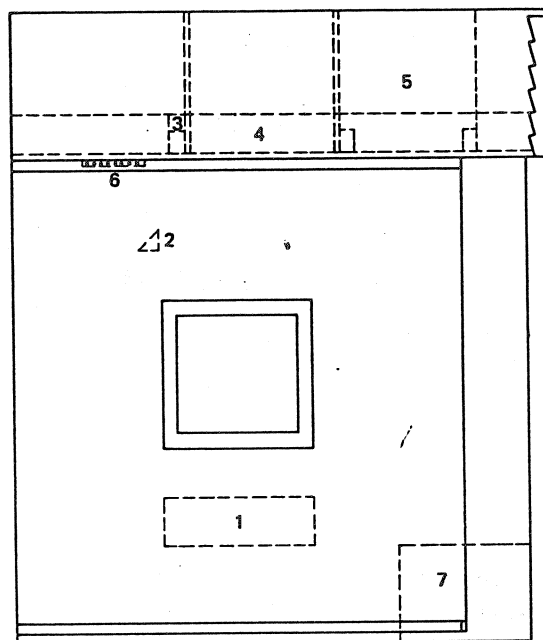
No. 5. Wind protection foil removed from insulation in ceiling. Forced draught at a speed of 1 m/s arranged at right angles to the outside.

Nr 6. Sexton st hål med 4 mm diameter.

No. 6 Sixteen 4 mm dia. holes.

Nr 7. Hörnparti borttaget.

No. 7. Corner portion removed.



5 Anvisningar för fältmätningar

5 Instructions for field measurements

5.1 Temperaturfall över provväggen

Förutsättningen för termograferingsarbetet är att ett tillräckligt temperaturfall föreligger i provväggen. Gjorda mätningar har visat att temperaturskillnaden $+10^{\circ}\text{C}$ utomhustemperatur. Termograferingssäsongen kan dock förlängas genom en tillfällig höjning av $+10^{\circ}\text{C}$ utomhustemperatur. Termograferingssäsongen kan dock förlängas genom en tillfällig höjning av rumstemperaturen före och under mätningen. Det är t.ex. fullt realistiskt att i nödfall utföra termografering av byggnader även under sommaren vid ca $+15^{\circ}\text{C}$ utomhustemperatur och mulet väder om rumstemperaturen genom uppvärmning kan hållas vid ca $+25^{\circ}\text{C}$ eller högre värden.

Förfarandet förutsätter vidare att i möjligaste mån *konstant lufttemperatur* råder utomhus före och under mätning. (Inomhustemperaturen bör givetvis även hållas konstant.) Vid noggrannare mätningar bör utomhuslufttemperaturen ej variera mer än $\pm 3^{\circ}\text{C}$ under mättiden och 3–4 dagar *före* mätning. Klart och soligt väder med stora lufttemperaturvariationer mellan dag och natt och direkt solbestrålning av provväggen är olämpligt för termografering. I de fall där man nöjer sig med att endast konstatera luftläckagefel kan i nödfall tillräckliga temperaturkontraster på provväggen uppnås även vid mindre temperaturfall över väggen än 10°C och en inom vidare gränser varierande utomhustemperatur.

5.2 Termografering utomhus och inomhus

En väggs ytemperatur kan vid fältmätning störas av en rad yttre klimatfaktorer vars effekter är svårbestämbara. Bland dessa kan nämnas:

1. Strålningsbyte med solen, rymden och angränsande föremål.
2. Nedfuktning av den undersökta väggytan genom nederbörd eller vattenångkondensering.
3. Luftströmning kring väggytan.

P.g.a. dessa faktorerers komplicerade natur har deras inverkan ej studerats närmare vid framställning av typtermogrammen. Det synes i stället vara ändamålsenligare att vid fältmätning inrikta sig på att genom särskilda åtgärder dämpa inverkan av klimatfaktorerna och invänta tidpunkt för termografering när gynnsammare förhållanden föreligger. Följande synpunkter kan därvid framläggas.

Vid termografering utomhus, dvs. av väggars utsida, är mätobjektet oskyddat mot väderfaktorer och stränga krav måste därför ställas på rådande väderförhållanden före och under mätarbetet. Eftersom ideala väderförhållanden av praktiska skäl icke alltid kan inväntas bör utomhustermografering normalt endast tillämpas vid orienterande mätningar, förslagsvis vid

5.1 Temperature drop across the test wall

It is a necessary condition of thermography that there should be a sufficient temperature drop in the test wall. Measurements performed have shown that the difference in temperature across the wall should not be less than 10°C , see also FIG. 13. In the case of normal room temperatures, this means an outdoor temperature of about $+10^{\circ}\text{C}$. The thermography can however be extended by temporarily raising the room temperature before and during measurements. It is for instance quite realistic to perform thermography of buildings in an emergency even during the summer at an outdoor temperature of around $+15^{\circ}\text{C}$ in cloudy weather if the room temperature can be kept at about $+25^{\circ}\text{C}$ or above by heating.

The procedure also stipulates that, as far as possible, the *air temperature should be constant* outdoors both before and during measurements. (Naturally, the indoor temperature must also be kept constant.) In the case of measurements of a more exact nature, the temperature of the air outdoors should not vary by more than $\pm 3^{\circ}\text{C}$ during the time measurements are carried out and for 3–4 days *prior to* the measurements. Clear, sunny weather with large variations in air temperature between day and night and direct sunshine on the test wall is unsuitable for thermography. In cases where it is sufficient only to locate points of air leakage, it is possible in an emergency to attain sufficient temperature contrasts on the test wall even when the drop in temperature is less than 10°C and the outdoor temperature varies within wider limits.

5.2 Thermography outdoors and indoors

The surface temperature of a wall during field measurements may be subjected to interference by a number of external climatic factors, the effects of which are hard to determine. Among these may be mentioned:

1. Exchange of radiation with the sun, space and adjacent objects.
2. Wetting of the wall surface being studied by precipitation or condensation of water vapour.
3. Flow of air around the wall surface.

Owing to the complex nature of these factors, their effects have not been studied in greater detail during production of the typical thermograms. It would instead appear more appropriate to endeavour during climatic factors by special measures and to postpone thermography until such time as conditions are more favourable. The following points of view may be put forward in this connection.

lokalisering av byggfel hos större husfasader, där man inte ställer högre krav på noggrannhet. Ytterligare en faktor talar mot utomhustermografering. Normalt föreligger lägre värmeövergångsmotstånd vid väggens utsida än vid väggens insida. Detta medför att bidraget till ytemperaturen från väggens värmemotstånd (2:a termen på högra sidan av ekv. (19) respektive (20)) är lägre på den kalla väggytan än på den varma, dvs. att kontrasterna hos temperaturfördelningen på den kalla väggytan blir mindre än på den varma. Man får alltså en sämre upplösning på mätresultatet vid mätning på den kalla ytan. *Noggrannare mätningar bör alltså endast utföras inomhus dvs. på väggens varma sida.* Vid inomhusmätning skyddas mätobjektet mot störande klimatfaktorer före och under mätningen så att större variationer i väderbetingelserna kan accepteras.

5.3 Praktiska anvisningar

5.31 Förberedelser

Väderförhållanden på mätplatsen följs antingen med hjälp av egna skrivande instrument eller uppgifter från SMHI¹ under ca 1 vecka. Skall säsongen för termografering utnyttjas effektivt bör systematisk väderobservation utföras parallellt för flera mätobjekt och fältmätningar påbörjas på mätplatser där gynnsamma väderförhållanden råder. Om tillräcklig stabilitet konstateras hos lufttemperatur, molnighet och vindförhållanden under minst 3 dygn och temperaturskillnaden mellan ute- och inneluft är lägst 10°C påbörjas mätningen. Ideala betingelser före och under mätning kan sägas vara mulet väder, oförändrad vindriktning och vindhastighet. En vindhastighet under 5 m/s och en konstans hos medellufttemperaturen bättre än $\pm 3^\circ\text{C}$ bör eftersträvas.

5.32 Förberedelser på mätplatsen

Ritningar över de undersökta väggarna granskas och ytmaterialets emissionstal utväljes ur TAB. 3. Inverkan av eventuella värmekällor (ingjutna rör, radiatorer o.d.) på den undersökta väggens temperatur kartläggs. Uppvärmningsradiatorer av lätt konstruktion kan eventuellt avstängas under termograferingen för att eliminera lokal vägguppvärmning. Vid måttillfället rådande temperaturfall och tryckfall noteras för den vägg som skall termograferas. Motsvarande »förväntade» termogram utväljes ur bilagorna 1–54 för provväggarna. Är de aktuella väggarna av annan konstruktion än de fyra i bilagorna upptagna typväggarna eller skiljer sig de undersökta väggarnas emissionstal väsentligt från dessa väggars emissionstal måste en bedömning av de förväntade värmebildernas utseende göras.

Före arbetets början noteras väderdata såsom lufttemperatur, molnighet, nederbörd, vindriktning, vindhastighet samt de undersökta väggarnas geografiska orientering.

5.33 Genomförande av termograferingen

Ställ in kameran i enlighet med tillverkarens anvisningar. Vid termografering av *flervåningsbyggnader*

In the case of thermography outdoors, i.e. of the outsides of walls, the object of measurement is unprotected from climatic factors and stringent demands must therefore be imposed as regards prevailing climatic conditions before and during measurements. Since for practical reasons work cannot always be postponed until weather conditions are ideal, outdoor thermography should normally only be used for preliminary measurements, for instance in locating building defects over large building facades where there are no great requirements as to accuracy. There is one more factor which counts against outdoor thermography, the fact that the surface resistance at the outside of a wall is normally lower than that at the inside. This means that the contribution by the thermal resistance of the wall (the second term on the right-hand side of Equations (19) and (20)) to the surface temperature is less on the cold wall surface than on the warm one, i.e. the contrasts in temperature distribution will be less pronounced on the cold wall surface than on the warm surface. There is therefore a less satisfactory resolution in the readings when measurements are performed on the cold surface. *Measurements of a more exact nature should therefore only be made indoors, i.e. on the warm surface of the wall.* During indoor measurements the object of measurement is protected from the interference due to climatic factors before and during the measurements, so that greater variations can be accepted in weather conditions.

5.3 Practical recommendations

5.31 Preparations

Weather conditions at the site of measurement should be kept under observation either with the aid of a plotting instrument owned by the surveying team or by means of information obtained from a weather forecasting station over a period of about 1 week. If the thermography season is to be made use of effectively, systematic observations of the weather should be carried out simultaneously at a number of sites, and field measurements begun at the sites where weather conditions are favourable. Measurements can be started if the air temperature, cloudiness and wind conditions exhibit sufficient stability for at least 3 days and there is a difference of at least 10°C between indoor and outdoor air temperatures. Cloudy weather, unchanged wind direction and wind velocity may be said to constitute ideal conditions before and during measurements. Wind velocity should be low 5 m/s and variations in the mean temperature should be less than $\pm 3^\circ\text{C}$.

5.32 Preparations on the site

The drawings of the walls to be studied are examined and the emissivity of the surface material is selected from TAB. 3. Effects due to any sources of heat (pipes cast into the wall, radiators etc.) on the temperature of the wall to be studied are investigated. Radiators of light construction may be turned off during thermography in order to eliminate local heat-

¹ Sveriges Meteorologiska och Hydrologiska Institut.

TAB. 3. Emissionstal, inom våglängdsområdet 2–5,6 μm , för de undersökta ytmaterialet.

Ytmaterial	Emissionstal
Träfiberplatta (porös), obehandlad	0,85
Träfiberplatta (hård), obehandlad	0,85
Plywood, obehandlad	0,83
Furu (hyvlad), obehandlad	0,83
Furu (ohyvlad), obehandlad	0,84
Gipsplatta, obehandlad	0,90
Spånplatta, obehandlad	0,90
Sandspackelfärg, vit	0,88
Oljefärg, grå matt	0,97
Oljefärg, grå blank	0,96
Oljefärg, svart matt	0,94
Oljefärg, svart blank	0,92
Plastfärg, vit	0,84
Plastfärg, svart	0,95
Kaduvlack, matt	0,93
Tapet (svagt mönstrad), ljusgrå	0,85
Tapet (svagt mönstrad), röd	0,90
Plasttapet, vit	0,84
Plasttapet, röd	0,94
Juteväv, ofärgad	0,87
Juteväv, grön	0,88
Fasadtegel, röd	0,92
Fasadtegel, gul	0,72
Puts, grå	0,92

De i tabellen angivna värdena har bestämts med en noggrannhet av $\pm 3\%$.

TAB. 3. Emissivities of the surface materials examined within the wavelength range 2–5.6 μm .

Surface material	Emissivity
Fibre board (porous), untreated	0.85
Fibre board (hard), untreated	0.85
Plywood, untreated	0.83
Redwood (wrought), untreated	0.83
Redwood (unwrought), untreated	0.84
Plasterboard, untreated	0.90
Chipboard, untreated	0.90
Filler, white	0.88
Oil paint, grey flat	0.97
Oil paint, grey gloss	0.96
Oil paint, black flat	0.94
Oil paint, black gloss	0.92
Plastic paint, white	0.84
Plastic paint, black	0.95
Varnish, flat	0.93
Wallpaper (slight pattern), light grey	0.85
Wallpaper (slight pattern), red	0.90
Plastic paper, white	0.84
Plastic paper, red	0.94
Hessian fabric, uncoloured	0.87
Hessian fabric, green	0.88
Facing bricks, red	0.92
Facing bricks, yellow	0.72
Rendering, grey	0.92

The tabulated values have been determined with an accuracy of $\pm 3\%$.

utförs, om väderförhållandena tillåter, orienterande mätningar från väggens utsida i syfte att snabbt lokalisera eventuella byggfel i ytterväggen. Vid utomhusmätning eftersträvas ideala väderförhållanden (se ovan). Solens inverkan kan elimineras genom mätning under natten. Man bör dock undvika att termograferas väggar som under dagen utsatts för direkt solbestrålning. Utomhusmätningen utförs som panorering. Med panorering avses exponering av väggytan från en eller ett par mätpositioner genom vridning av kameran. Eventuella misstänkta fels läge noteras på väggens ritning. Om utrymmet kring mätobjektet tillåter kan kameran placeras så att hela väggen ses samtidigt. Därvid måste man räkna med att kamerans upplösningsförmåga minskar så att vissa mindre byggfel kan förbli oupptäckta. Om säkrare dokumentation av misstänkta byggfel önskas utförs efter undersökning enligt ovan en termografering från väggens insida av de väggavsnitt som konstaterats innehålla misstänkta fel.

Även inomhusmätningen påbörjas med panorering. Ställ in kamerans mätområde så att väggens »normala» ytemperatur motsvarar gråtonsskalans högre område och de lägsta temperaturerna på väggen (gällande t.ex. hörnpartier och eventuella byggfel) motsvarar gråtonsskalans lägre område. Påträffas väggavsnitt med misstänkta byggfel avfotograferas värmebilden på oscilloskopskärmen. Fotograferingen omfattar en »gråtonsbild» och minst en isotermbild. Isotermerna förläggs därvid dels på väggens intakta del, dels på felpartiets lägsta temperatur eller på temperatur för karakteristiskt väggavsnitt. Är något väggparti av särskild betydelse kan väggpartiets hela temperaturfördelning återges med färgtermogram.

För bestämning av absolut temperaturfördelning hos termogrammen kan en referenstemperatur på

ing of the wall. The drops in temperature and pressure prevailing at the time of measurement are noted for the wall to be subjected to thermography. The corresponding »expected» thermogram is selected from Appendices 1–54 for the test walls. If the walls in question have a construction different from the four typical walls represented in the Appendices, or if the emissivities of the walls under study are appreciably different from the emissivities of these walls, an assessment must be made of the appearance of the expected thermograms.

Before work is started, weather data such as air temperature, cloudiness, precipitation, wind direction, wind velocity, and also the geographical orientation of the walls being studied, must be recorded.

5.33 Procedure during thermography

Adjust the camera according to the maker's instructions. During thermography of *buildings of several stories*, preliminary measurements should be carried out from the outside of the wall, if weather conditions permit, in order to locate quickly any building defects which there may be in the external wall. Endeavours should be made in the case of outdoor measurements to ensure that weather conditions are ideal (see above). The effect of the sun can be eliminated by taking readings during the night, but thermography of walls which have been subjected to direct sunlight during the day should be avoided. The measurements should be taken by panning the camera, which means that the wall surface as a whole is photographed from one or perhaps two positions by turning the camera. The positions of any suspected defects should be noted on the drawing of the wall. If space around the object of measurement permits, the camera may be set up so that the whole surface

väggen bestämmas antingen medelst kontakttermometer eller särskild referensstrålare med känd temperatur och emissionstal. (Både AB AGA och AB Bofors tillverkar sådana referensstrålare.) Beräkning av temperaturskillnad utförs i enlighet med exemplet i avsnitt 2.3, varvid ifrågavarande kameras kalibreringskurva (se FIG. 6) och emissionstalet för det aktuella byggnadsmaterialet utväljs ur TAB. 3 enligt avsnitt 2.4. Observera att om mätobjektets yta sammansätts av flera ytmaterial (t.ex. tapet och tegel) skall varje uppmätt ytemperatur tillordnas motsvarande tillämpligt emissionstal.

De sålunda framställda termogrammen (fotografier) av misstänkta byggfel jämförs summariskt med förväntade temperaturfördelningar för ifrågavarande väggtyp och klimatfall. Typtermogram enligt bilagorna 1–54 används för detta. Vid jämförelsen bedöms de faktorer som påverkar värmeövergångskoefficienten (α -värdet) vid väggen genom orienterande uppmätning av luftströmningsförhållanden i rummet medelst varmtrådsanemometer och bedömning av värmestrålningsförhållanden. Finns anledning att misstänka större skillnad mellan α -värdet i det aktuella mätfallet och det α -värde som legat till grund för framställningen av typtermogrammet noteras detta.

Kan de misstänkta byggfelen inte förklaras med konstruktionens utförande enligt ritning, variationer hos emissionstal eller α -värde, konstateras att sannolik avvikelse föreligger från önskat utförande. Felets art bestäms genom jämförelse med typtermogram över vanliga byggfel (BIL. 1–54). Tyder termogrammens utseende på luftläckage genom väggen kan feltypen bekräftas genom lufthastighetsmätning medelst varmtrådsanemometer. Det är tillfyllest med endast kvalitativ mätning i detta fall eftersom det uppmätta mätvärdet ändå blir mycket osäkert på grund av ogynnsamma mätbetingelser. Tyder termogrammens utseende på isolerfel (värmeläckage) kan man, där detta är möjligt, även utföra kvantitativ bestämning av värmemotståndsfördelning på det förmodat felaktiga väggavsnittet med hjälp av värme-flödesmätare.

Vid undersökning av småhus utförs termografering med fördel uteslutande inomhus. Arbetsproceduren blir densamma som angivits ovan.

Rapporten från en termografering skall innehålla följande punkter:

1. Husets orientering i förhållande till väderstrecken.
2. Väderdata under 4–5 dygn före termograferingen och vid termograferingstillfället.
3. Inomhustemperatur och lufttemperaturfall över provväggen.
4. Tryckfall över provväggen.
5. Typ av ytmaterial hos provväggen.
6. Eventuellt anges värme-flöde och temperaturfall över provväggen för olika väggpartier.
7. Termogram av väggpartier som innehåller misstänkta fel.

of the wall is seen at the same time, although it must be borne in mind that this will cause a decrease in the resolution capacity of the camera, with the result that certain smaller building defects may remain undetected. If it is required that suspected building defects should be documented in a more certain manner, the examination outlined above should be followed by thermography from the inside of the wall of those parts of the wall in which it is suspected that there are defects.

Indoor measurements should also be started by panning the camera. Adjust the measuring range of the camera so that the »normal» surface temperature of the wall corresponds to the higher range of the grey scale and the lowest temperatures on the wall (those applicable to e.g. corners and building defects) to the lower range of the grey scale. If a wall section with a suspected building defect is found, a photograph is taken of the thermal image shown on the screen of the oscilloscope. Photographs should be taken of one monochrome image and at least one isotherm image. The isotherms should be imposed partly over the intact portion of the wall and partly on the lowest temperature of the portion containing the defect, or on the temperature of a characteristic section of the wall. If some portion of the wall is of particular importance, the temperature distribution of the whole wall section may be illustrated by means of a colour thermogram.

If the absolute temperature distribution of the thermogram is to be determined, a reference temperature on the wall can be determined either by means of a contact thermometer or a special reference emitter of known temperature and emissivity. (Both AB AGA and AB Bofors manufacture such reference emitters.) Calculation of the temperature difference is done in accordance with the example in Section 2.3, the calibration curve of the camera in question (see FIG. 6) and the emissivity of the appropriate building material being selected from TAB. 3 in Section 2.4. Note that if the surface of the object of measurement is composed of a number of materials (e.g. wallpaper and brick) every surface temperature which is measured must be related to the corresponding applicable value of the emissivity.

The thermograms (photographs) of suspected building defects produced in this way are briefly compared with the expected temperature distributions for the type of wall and climatic condition in question. The typical thermograms in Appendices 1–54 are to be used for this purpose. During the comparison, the factors which affect the surface coefficient of heat transfer (the value of α) at the wall are assessed by means of background measurements of the air flow conditions in the room with a hot-wire anemometer and assessments of thermal radiation conditions. If there is reason to suspect that there is a major difference between the value of α in the case being considered and the value of α on which production of a typical thermogram was based, a note is to be made to this effect.

If the suspected building defect cannot be explained on the basis of the construction of the structure

5.34 Glas- och metallytor

Yttertemperaturmätning på blanka metall- och glasytor medför särskilda mätproblem. Beträffande mätning på glas kan anföras följande. Som framgår av FIG. 26 är fönsterglas transparent för strålning inom våglängdsområdet 0–5 μm , Wolfe (1965). Glaset genomsläpper således strålning även inom en del av IR-kamerans känslighetsområde (2–5,6 μm). Utförs termografering av fönster på vanligt sätt kommer termogrammet därför att innehålla genom glaset transmitterad värmestrålning. Man mäter inte endast glasytans temperatur utan även temperaturen för bakomliggande föremål. Mätproblemet löses lämpligen genom införande av strålningsfilter på kameran som avskärmar infallande strålning inom våglängdsområdet 0–5 μm . Kameratillverkaren levererar erforderlig utrustning.

Mätning av ytemperaturen för *blanka metallytor* erbjuder ett svårloslöst mätproblem. Emissionstalet för blank metall är nämligen så lågt, ca 0,1, att större delen av den strålning som avges från ytan utgör reflekterad strålning från omgivningen. I princip kan IR-kamera icke användas för denna mätuppgift utan att mätobjektets emissionstal ökas. Detta kan ske förslagsvis genom anbringande av en för strålningen opak, tunn plastfilm med högt emissionstal på mätobjektets yta.

5.35 Metodens tillförlitlighet

Mätresultaten från ett termograferingsarbete avses bl.a. kunna användas som bevismaterial vid tvister. Det är därför av grundläggande intresse att klarlägga risken för dels att väsentliga byggfel förblir oupptäckta vid undersökningen, dels att de medelst termografering lokaliserade misstänkta byggfelen vid upprivning i själva verket icke visar sig vara byggfel (»kvasibyggbfel»).

Det har tidigare framhållits att vissa mindre isolerfel ej kan upptäckas om tillgänglig temperaturgradient genom väggen är för liten. Exempel på minsta re-

according to the drawings, variations in emissivity or the value of α , it is evident that the discrepancy is probably due to a difference in construction. The type of defect is determined by comparison with typical thermograms for common building defects in Appendices 1–54. If the appearance of the thermogram indicates leakage of air through the wall, this type of defect can be confirmed by air flow measurement with a hot-wire anemometer. Qualitative measurement alone is sufficient in this case since the readings obtained will in any case be uncertain due to unfavourable measuring conditions. If the appearance of the thermogram indicates a defect in insulation (leakage of heat), it is also possible, if this is feasible, to carry out a quantitative determination of the distribution of thermal resistance on the section of wall containing the supposed defect with the aid of heat flow meters.

When *single-family dwellings* are investigated, it is best if thermography is performed only indoors. The operating procedure is the same as that described above.

A report of a thermography examination must include the following:

1. Geographical orientation of the building
2. Weather data for the period beginning 4–5 days prior to measurements and during measurements
3. The indoor temperature and the drop in air temperature across the wall tested
4. Pressure drop across the wall tested
5. The type of surface material in the wall tested
6. If necessary, the heat flow and temperature drop across the wall tested are to be quoted for different sections of the wall
7. Thermograms of sections of the wall containing suspected defects.

5.34 Surfaces of glass and metal

Measurements of surface temperature on glass and shiny metal surfaces entail special problems. The following may be stated with regard to measurements on glass. As will be seen from FIG. 26, window glass is transparent to radiation within the wavelength range 0–5 μm , Wolfe (1965). Glass therefore also transmits radiation within part of the sensitivity range (2–5.6 μm) of an IR-camera. If thermography is therefore carried out in the usual manner, the thermogram of a window will contain thermal radiation transmitted through the glass, and the temperature measured will be not only that of the glass surface but also that of objects behind the glass surface. This problem of measurement is best solved by fitting a radiation filter to the camera which screens incident radiation within the wavelength range 0–5 μm . The camera manufacturer supplies the necessary equipment.

The problems involved in measuring the surface temperature of *shiny metal surfaces* are difficult to solve, since the emissivity of shiny metal is so low, about 0.1, that most of the radiation emitted by the

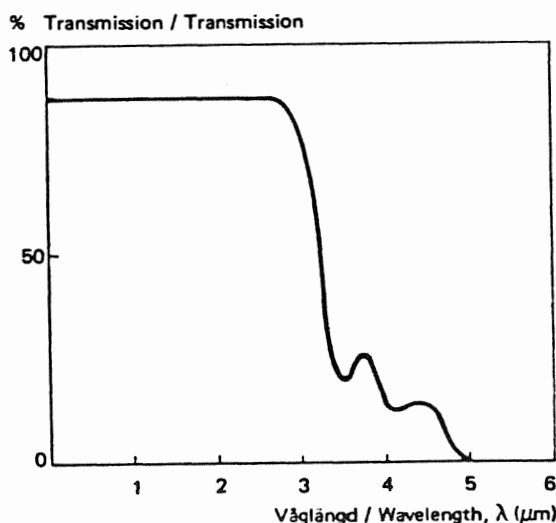


FIG. 26. Transmissionskurva för strålning genom fönsterglas.

Transmission curve for radiation through window glass.

duktion av väggens värmemotstånd som ej kan upptäckas med termografering anges i FIG. 13. När det gäller otätheter för luftströmning är risken mycket liten för att felen blir oupptäckta. Även vid temperaturgradienter under 10°C över provväggen erhålls vid undertryck på väggens varma sida tillräcklig nedkylning av väggytan för att IR-kameran skall kunna indikera felet.

Risken för fastställande av »kvasibyggsfel» av typen isolerfel föreligger teoretiskt i följande fall:

1. Termografering utförs utan att termisk jämvikt inväntats.
2. Värmeövergångskoefficienten (α -värdet) på provväggytan varierar så att temperaturvariationer på ytan erhålles.
3. Emissionstalet på väggytan varierar så att skenbara temperaturvariationer på ytan erhålles.

Av de nämnda felorsakerna kan endast α -värdets inverkan i princip medföra svårigheter eftersom α -värdesfördelningen på mätobjektets yta oftast ej är känd vid termograferingen. Man kan dock av termogrammens utseende oftast sluta sig till om risk finns att α -värdet påverkar temperaturfördelningen. Har de mörka partierna oregelbunden form och tämligen distinkta konturer är det oftast frågan om isolerfel eller köldbryggor (se BIL. 17, 18 och 19). Endast i de fall där övergången mellan ljusare och mörkare partier på termogrammet är diffus behöver inverkan av α -värdesvariationen befaras. I en kommande undersökning skall närmare klarläggas vilka feltolkningsmöjligheter som α -värdesändringar kan medföra.

Risken för »kvasibyggsfel» av typen otätheter i väggar är i det närmaste obefintlig. Omfattande undersökningar av Svenska Riksbyggen (ca 4 000 termogram av bostadshus har tagits) har visat dels att ca 85 % av förekommande byggsfel utgör otäthetsfel, dels att i samtliga fall där byggsfel har misstänkts på termogrammen fel också har konstaterats vid upprivning av väggarna, Axén (1968).

Sammanfattningsvis kan sägas följande:

Misstänkta byggsfel av typen luftläckage genom otäta fogar och fel av typen kombination av luftläckage och »rent» isolerfel kan med tillräcklig säkerhet verifieras, särskilt när undertryck åstadkommes i rummet. Byggsfel av typen otillräcklig isolering kräver större omsorg vid planering och genomförande av termograferingen. Iakttagas ovan angivna regler och tillämpas jämförelse med »förväntade» termogram kan metoden sägas vara tillförlitlig vid fastställande av grova isolerfel. Där mindre avvikelser från förväntade bilder konstateras rekommenderas värmeflödesmätning på de kritiska väggavsnitten innan byggsfelet fastställs. Allmänt kan sägas att under termograferingsarbetets första skede bör värmeflödesmätning på platsen tillgripas oftare för att samla erfarenheter. Användning av denna hjälpmetod kan sedan successivt begränsas till allt mer diskutabla fall.

surface is reflected radiation from surrounding objects. In principle, an IR-camera cannot be used for such measurements without the emissivity of the object of measurement being increased. This can be done for instance by fitting over the surface of the object of measurement a thin film of plastic of high emissivity which is opaque to the radiation.

5.35 The reliability of the method

It is intended that one of the purposes for which it should be possible to use the measurement results from a thermographic examination will be as evidence in cases of dispute. It is therefore of fundamental interest that it should be quite clear what the risks are that essential building defects will remain undetected during an investigation and that suspected building defects which are located by means of thermography will be found, when the structure is opened up, to be not building defects but »quasi-building defects».

It has been pointed out before that certain minor defects in insulation cannot be detected if the available temperature gradient across the wall is too small. Examples of the least reduction in the thermal resistance of a wall which cannot be detected by means of thermography are given in FIG. 13. With regard to points of leakage which allow the flow of air, the risk that the defect will not be found is very small. Even when the temperature gradient across the wall tested is less than 10°C , the warm side of the wall, if it is at a lower pressure than the cold side, is cooled down sufficiently for the IR-camera to be able to indicate the presence of the defect.

There is a theoretical risk that a »quasi-building defect» of the insulation defect type will be found in the following cases:

1. When thermography is carried out without thermal equilibrium being established
2. When the surface coefficient of heat transfer (α) over the surface of the wall tested varies so that there are variations in temperature over the surface
3. When the emissivity varies over the surface of the wall so that apparent variations in temperature are obtained over the surface.

Of the above sources of error, it is in principle only the effect of α which may cause difficulties since the distribution of the value of α over the surface of the object of measurement is very often not known when the thermographic examination is performed. It is however usually possible to decide on the basis of the appearance of the thermogram whether there is any risk of the value of α affecting the temperature distribution. If the dark places have an irregular shape and fairly distinct contours, it is usually a matter of a defect in insulation or a thermal bridge (see Appendices 17, 18 and 19). It is only when the transition between light and dark places on the thermogram is indistinct that there is any need to suspect an effect due to variation in the value of α . An investigation being planned will elucidate in greater detail what are the possibilities of erroneous inter-

pretation due to alterations in the value of α .

There is practically no risk that »quasi-building defects» will be found due to leakage of air through walls. Comprehensive investigations carried out by the Co-operative Building Organization of the Swedish Trade Unions, in which about 4000 thermograms of residential buildings were taken, have shown that about 85 % of all building defects found are of this nature and also that in all cases where a building defect was suspected on the basis of the thermogram, such a defect was actually found when the wall in question was opened up, Axén (1968).

Summing up, the following may be said:

Suspected building defects of the type where there is leakage of air through joints and defects of the type where there is a leakage of air in combination with a »pure» defect in insulation can be verified with sufficient reliability, especially when the pressure in the room is lower than that outside. Building defects of the type where insulation is insufficient necessitate greater care in planning and performing the thermographic examination. If the above rules are observed and a comparison is made with expected thermograms, the method may be said to be reliable for the location of major defects in insulation. Where there are minor deviations from the expected configuration, it is recommended that heat flow measurement should be carried out over the critical sections of the wall before the building defect is finally confirmed. In general, it may be said that heat flow measurements in situ should be carried out often during the introductory stage of thermographic work in order to acquire experience, while at a later stage the use of this aid can be gradually confined to cases of a more doubtful nature.

6 Exempel på bedömning av byggfel

FIG. 27. Uppställning av kamerautrustning vid termografering av väggparti vid takhörn. Termogrammet återges ovan på bildskärmen.

Setting up of camera equipment in thermography of part of the wall at the corner of the ceiling. The thermogram is reproduced above on the screen.

6.1 Tillvägagångssätt vid bedömning av termogram taget vid fältmätning

Som exempel på hur en byggkontroll medelst termografering sker i fält redogörs nedan för två konkreta fall:

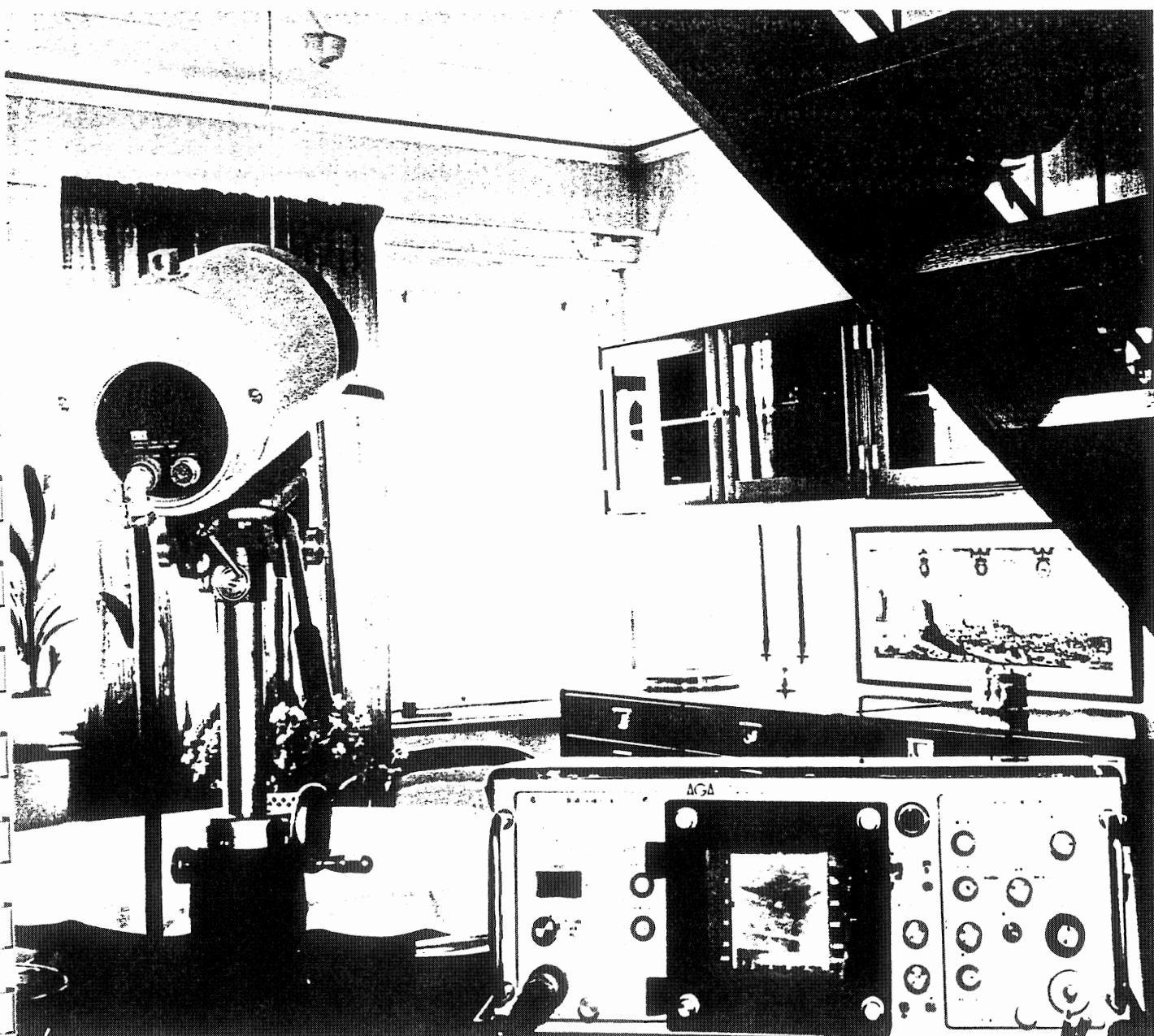
Vid panorering över ett väggavsnitt upptäcks ett ytparti där byggfel kan föreligga. Kameran riktas mot detta väggparti och ett termogram tas (se FIG. 27).

6 Examples of assessments of building defects

6.1 Procedure for the assessment of a thermogram obtained during measurements in situ

Two actual cases will be described below to provide examples of how a building is checked in situ by means of thermography.

When the camera is panned over a section of a wall, a section is found which may contain a building defect. The camera is directed towards this section of the wall and a thermogram is taken (see FIG. 27).



Exempel 1 (FIG. 28)

Väggkonstruktionen är enligt konstruktionsritningen av typ regelvägg med 120 mm mineralullsisolering med en beklädnad av fasadtegel på utsidan och gipskiva på insidan.

Ytmaterialet på insidan består av en svagt mönstrad ljus tapet. Emissionstalet väljes till 0,85 enligt TAB. 3.

Ett termogram av väggen visas i FIG. 28a:

Med utgångspunkt från de uppmätta mätbetingelserna, temperatur ute och inne samt lufttrycket i provrummet, uppsöks i registret över typtermogram (BIL. 1–54) det mätfall som närmast överensstämmer med det ytavsnitt av väggen som termograferats och de aktuella mätförhållandena. I detta fall väljes regelvägg nr 1 (BIL. 6). Det valda termogrammet jämförs med typtermogrammet för felfri konstruktion, FIG. 28b.

Skillnad i termogrammens utseende konstateras. Ytpartiet vid takfoten framträder tydligare i termogram *b* än i termogram *a*. Detta beror på att konstruktionen enligt termogram *a* är försedd med elektriska värmeslingor som har uppvärmt taket något strax före mättillfället. Fönstret framträder dessutom i termogram *b* som en mörk yta. Konstruktionsritningen kan ej förklara det rektangulära nedkylda väggpartiet i termogram *a*. Man misstänker att ett isolerfel föreligger.

Jämförelse göres därför med termogram för samma väggavsnitt av regelvägg nr 1 med inbyggda fel och vid samma mätbetingelser som för termogram *b* (BIL. 19).

Här framträder en rektangulär nedkyld yta liknande den i termogram *a*. I termogram *c* beror nedkylningen av den rektangulära ytan på att isolering är borttagen (fel nr 7 enligt FIG. 22).

Den rektangulära formen är något deformerad på grund av viss luftcirkulation i det uppkomna hålrummet.

Slutsats: Felet i termogram *a* är av samma typ som fel nr 7 enligt FIG. 22 för regelvägg nr 1.

Exempel 2 (FIG. 29)

Väggkonstruktion: Regelvägg med 120 mm mineralullsisolering, med en beklädnad av fasadtegel på utsidan och gipsskiva på insidan.

Ytmaterialet på insidan består av en slät ljus tapet. Emissionstalet väljes till 0,85 enligt TAB. 3.

Termogram enligt FIG. 29a jämföres med lämpligt typtermogram. Regelvägg nr 1 (BIL. 6), felfri konstruktion (FIG. 29b) är taget vid ungefär samma mätbetingelser som för termogram *a* och av ytavsnitt vid golvlist. Skillnad i termogrammens utseende kan konstateras. Ytpartiet vid golvlisten har i termogram *a* avvikande utseende jämfört med motsvarande ytparti i termogram *b*. Konstruktionsritningen kan ej ge en rimlig förklaring till denna avvikelse.

Jämförelse görs med termogram från samma väggavsnitt av regelvägg nr 1 med inbyggda fel och vid samma mätbetingelser som för termogram *b* (BIL. 19).

Här är termogrammens utseende av ytpartiet vid

Example 1 (FIG. 28)

According to the design drawing, the wall construction is of the framed cladding panel type containing mineral wool insulation 120 mm thick, with a skin of facing bricks on the outside and plasterboard on the inside.

The surface material on the inside consists of a slightly patterned light wallpaper. According to TAB. 3, the value of emissivity is 0.85.

A thermogram of the wall is shown in FIG. 28a.

On the basis of the measured conditions, the temperature outdoors and indoors and the air pressure in the test room, the measuring condition which is in closest agreement with the type of wall thermographed and with the prevailing measuring conditions, is selected from the folder of typical thermograms (Appendices 1–54). The thermogram selected in this case is that for framed cladding panel No 1, (Appendix 6). The selected thermogram is compared with the typical thermogram applicable to a construction without defect, FIG. 28b.

Differences are found in the appearances of the thermograms. The surface of the wall at the eaves is more prominent in thermogram *b* than in thermogram *a*. This is due to the fact that the structure according to thermogram *a* is equipped with electric heating wires which slightly warmed the ceiling immediately prior to measurements. In addition, the window in thermogram *b* appears as a dark surface. The design drawing cannot explain the presence of the colder rectangular area of the wall in thermogram *a*. It is suspected that there is a defect in insulation.

A comparison is therefore made with thermograms of the same section of framed cladding panel No 1 with artificial defects, for the same measuring conditions as those applicable to thermogram *b* (Appendix 19).

A colder rectangular area similar to that in thermogram *a* is found. This cooling-down of the rectangular area in thermogram *c* is due to removal of the insulation (Defect No 7 according to FIG. 22).

The rectangular shape is somewhat deformed owing to some air movement in the cavity formed.

Conclusion: The defect in thermogram *a* is of the same type as defect No 7 according to FIG. 22 for framed cladding panel No 1.

Example 2 (FIG. 29)

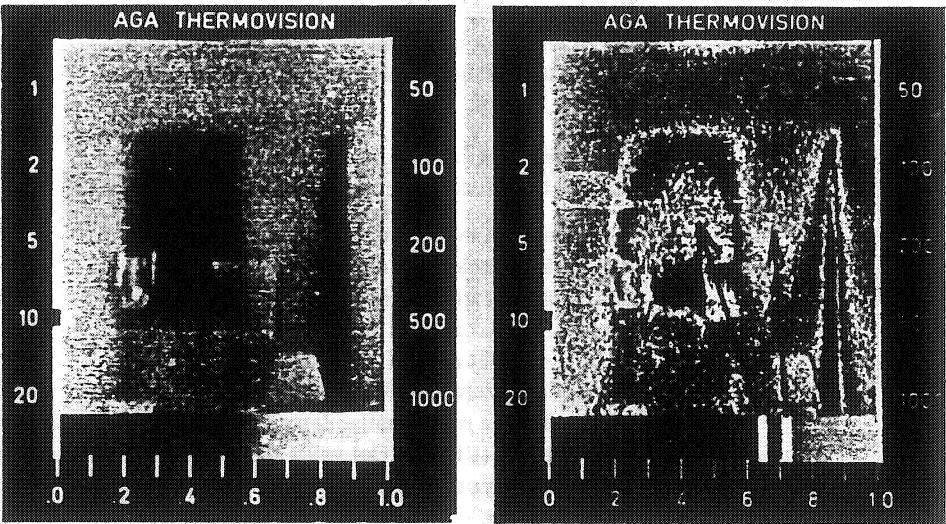
Wall construction: Framed cladding panel containing mineral wool insulation 120 mm thick, with a skin of facing bricks on the outside and plasterboard on the inside.

The surface material on the inside consists of a light-coloured smooth wallpaper. According to TAB. 3, the emissivity is 0.85.

The thermogram according to FIG. 29a is compared with the appropriate typical thermogram. That of framed cladding panel No 1 without defect (FIG. 29b), showing the section near the skirting board, is

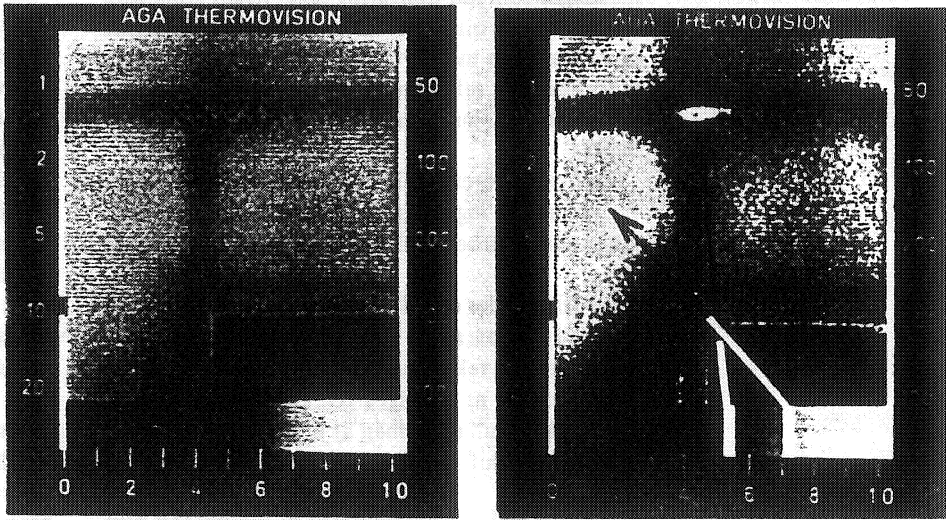
FIG. 28. Exempel på bedömning av termogram.
Examples of assessment of a thermogram.

$t_i - t_u = 20^{\circ}\text{C}$
 $p_i - p_u = + 50 \text{ N/m}^2$
 $\Delta t = 4.2^{\circ}\text{C}$



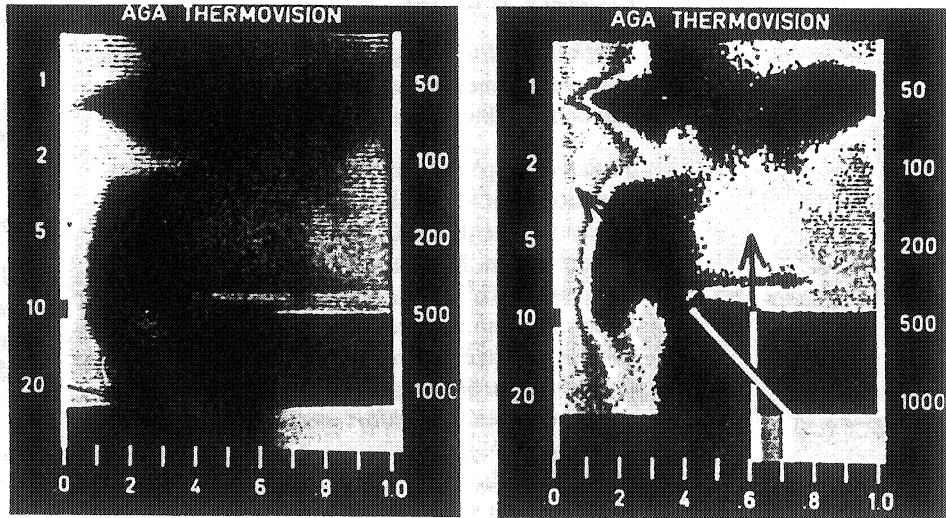
a. Termogram taget vid fältmätning av väggparti vid vāghörn. Vāl markerad nerkyld rektangulār yta framtrāder i mitten av termogrammet (grātonsbild till vänster, termogrammbild till höger).
a. Thermogram taken during field measurements on part of a wall near the corner. A well-defined rectangular cold area is shown in the middle of the thermogram (monochrome image to the left, thermogram image to the right).

$t_i - t_u = 26^{\circ}\text{C}$
 $p_i - p_u = + 50 \text{ N/m}^2$
 $\Delta t = 7.5^{\circ}\text{C}$



b. Typtermogram av väggavsnitt B för regelvägg nr 1, felfri konstruktion, se termogram B1-4, BIL. 6
b. Typical thermograms of wall section B for framed cladding panel No. 1 with correct design, see Thermograms B1-4, APP. 6.

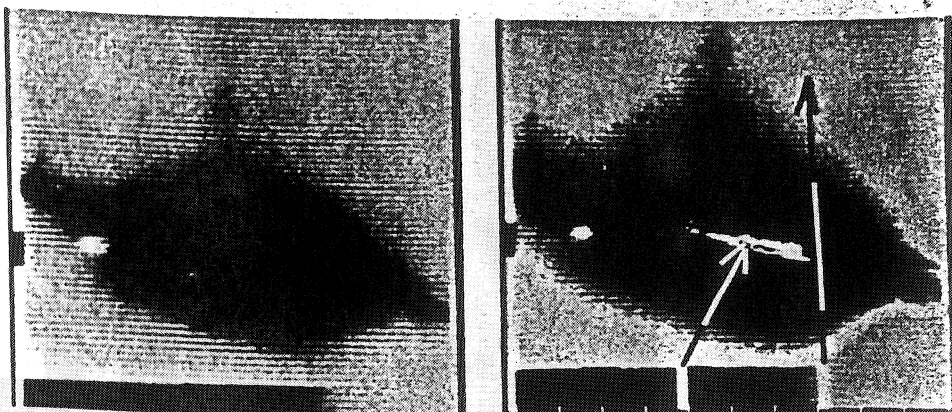
$t_i - t_u = 26^{\circ}\text{C}$
 $p_i - p_u = + 50 \text{ N/m}^2$
 $\Delta t = 3.1^{\circ}\text{C}$



c. Typtermogram av väggavsnitt B för regelvägg nr 1 med inbyggda fel, se termogram B1-3, BIL. 19. Den nerkylda rektangulāra ytan ovanför vänstra halvan av fönstret ār orsakad av fel nr 7 enligt FIG. 22.
Typical thermograms of wall section B for framed cladding panel No. 1 with deliberate faults, thermograms B1-3, APP. 19. The cold rectangular area above the left half of the window is due to fault No. 7 according to FIG. 22.

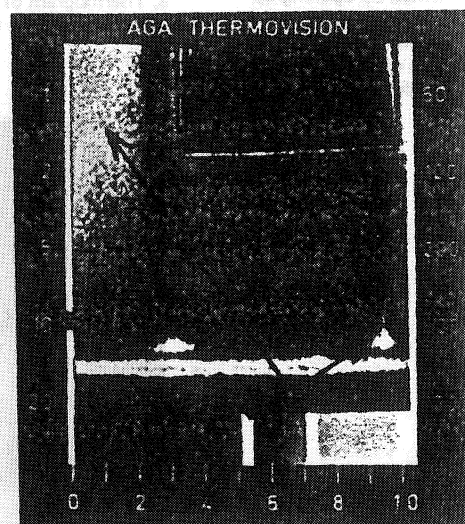
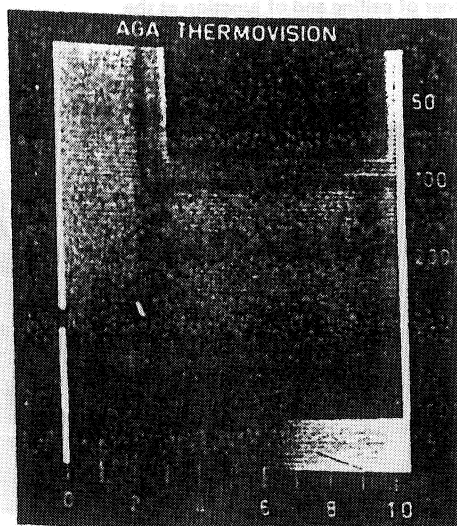
FIG. 29. Exempel på bedömning av termogram.

Example of assessment of a thermogram.



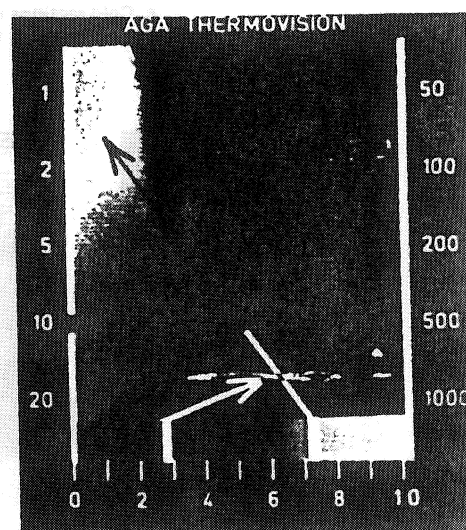
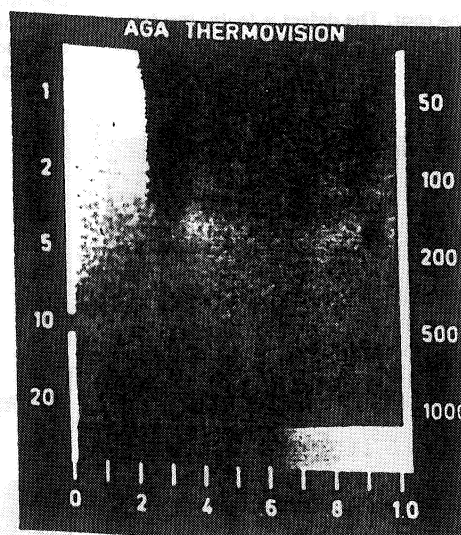
a. Termogram av ytparti vid golvlister. Uppmätt luftfartshastighet med anemometer vid golvlister 0,3–0,4 m/s (gråtonsbild till vänster, termogrammbild till höger).

a. Thermogram of section near skirting board. Air velocity measured with an anemometer = 0.3–0.4 m/s. (Monochrome image to the left, thermogram image to the right).



b. Typtermogram av väggavsnitt C för regelvägg nr 1 (felfri konstruktion), se termogram C1–4, BIL. 6.

b. Typical thermograms of wall section C for framed cladding panel No. 1 (correct design), see thermograms C1–4, APP. 6.

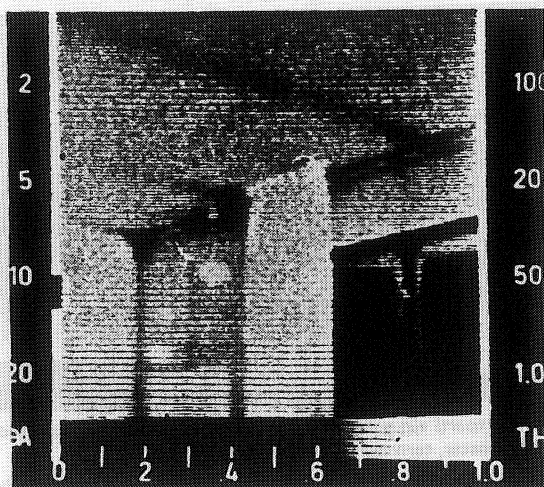


c. Typtermogram av väggavsnitt C för regelvägg nr 1 med inbyggda fel, se termogram C1–3, BIL. 19. Ytparti vid golvlister är nerkyllt p g a luftläckage genom en springa mellan provvägg och golv. Den »standade» konturen framträder ej här då luftströrelsen genom springan är svag och har en jämn fördelning längs läckageavsnittet.

c. Typical thermograms of wall section C for framed cladding panel No. 1 with deliberate faults, see thermograms C1–3, APP. 19. The section near the skirting board is colder due to leakage of air through a gap between the test wall and the floor. The »standed» contour cannot be seen here since the air flow through the gap is slight and is uniformly distributed along the gap.

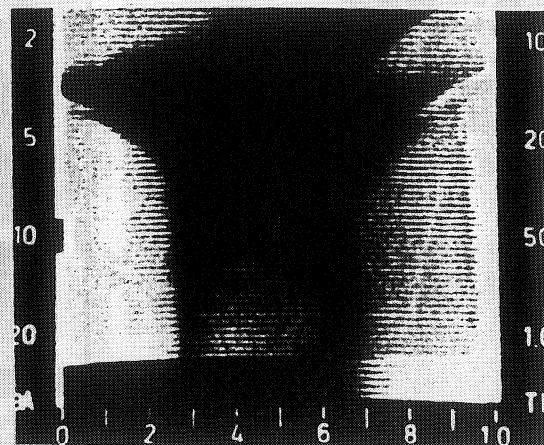
FIG. 30. Exempel på termogram tagna vid, under vintersäsongen 1970-71, utförda fältmätningar. Under respektive termogram anges kortfattat byggtyp. I de fall man ej kunnat verifiera bygget genom att riva väggen och okulärbesiktiga den har detta i texten angetts med förmodat byggtyp.

Examples of thermograms taken during field measurements in the 1970-71 winter season. A brief description of the type of building defect is given underneath each thermogram. In cases where the building defect could not be confirmed by opening up the wall and visually inspecting it, the supposed type of building defect has been given.



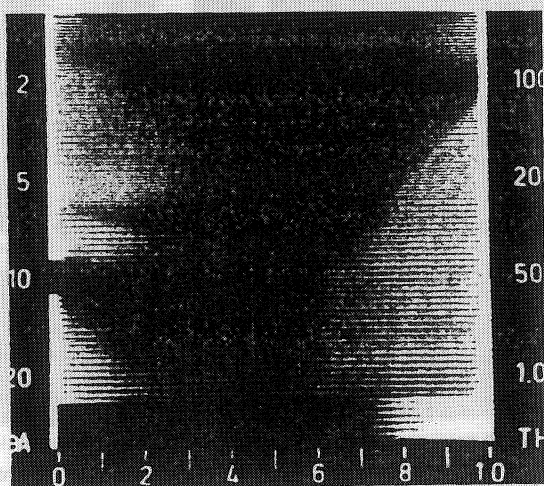
a. Termogram av takhorn och av anslutning vid takfot. Felfri konstruktion.

a. Thermogram of corner of ceiling and of junction at the eaves. No fault in the construction.



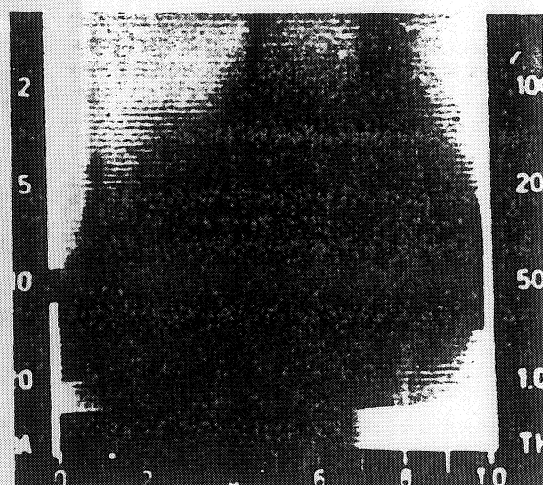
b. Nedkylt ytparti vid takfotsanslutning. Bygget beror på bristfällig isolering mot regel på vindbjälklag.

b. Cold section at the junction with the eaves. The defect is faulty insulation on the attic floor joists.



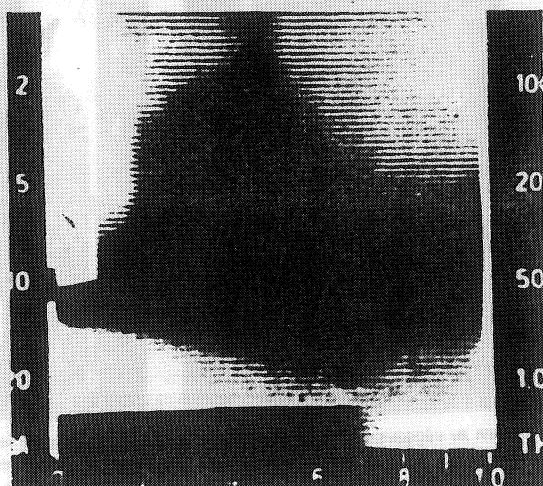
c. Nedkylta ytpartier i tak. Bygget beror på bristfällig isolering kring takstol. Kall luft sprider sig i glespanelen.

c. Cold sections in the roof. The defect is faulty insulation around the roof truss. Cold air spreads between the joists.



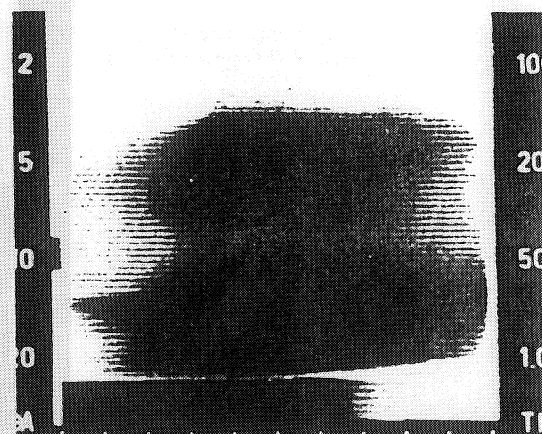
d. Nedkylt ytparti vid golvhörn. Orsaken är att isoleringsskivorna i facken mellan reglarna ej ansluter mot syllens kombinerat med luftläckage vid bjälklagsanslutning. Uppmätt luftfart vid golvlister 1,0-1,2 m/s.

d. Cold section at the corner of the floor. The cause is that the insulation slabs between the studs are not in contact with the bottom member, combined with leakage of air at the junction with the floor. Air velocity measured at the skirting board = 1.0-1.2 m/s.



e. Nedkylt ytparti vid golvlister. Bygget är orsakat av luftläckage. Uppmätt luftfart vid golvlister 0,3-0,5 m/s.

e. Cold section at the skirting board. The defect is due to leakage of air. Air velocity measured at skirting board = 0.3-0.5 m/s.

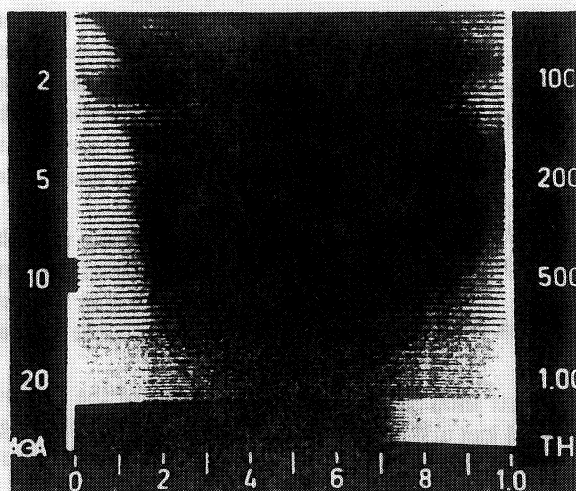


f. Nedkylt ytparti mitt på väggen vid uttag för eldos. Förmodat byggtyp är bristfälligt utförande av isolering i facket mellan reglarna kombinerat med luftfart i konstruktionen.

f. Cold section in the middle of the wall near the junction box. The supposed building defect is faulty insulation between the studs combined with air movement in the construction.

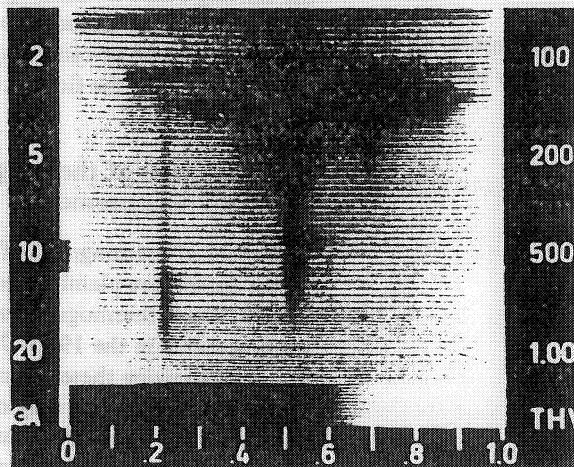
FIG. 31. Exempel på termogram tagna vid, under vintersäsongen 1970–71, utförda fältmätningar. Under respektive termogram anges kortfattat byggtyp. I de fall man ej kunnat verifiera bygget genom att riva väggen och okulärbesiktiga den har detta i texten angetts med förmodat byggtyp.

Examples of thermograms taken during field measurements in the 1970–71 winter season. A brief description of the type of building defect is given underneath each thermogram. In cases where the building defect could not be confirmed by opening up the wall and visually inspecting it, the supposed type of building defect has been given.



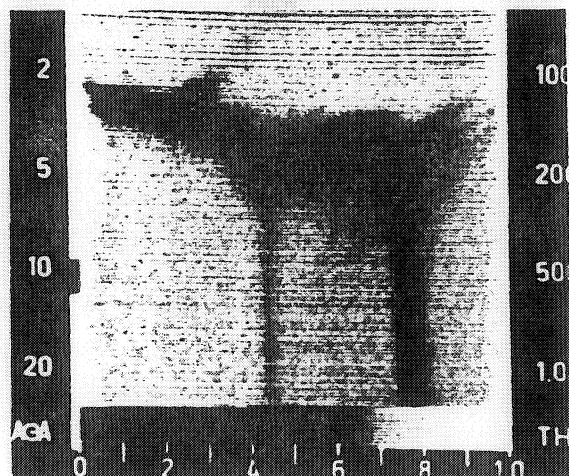
a. Nedkylt ytparti vid takfot. Bygget är orsakat av luftläckage. Uppmätt lufthastighet vid taklist 1,0–1,2 m/s.

a. Cold section at the eaves. The building defect is due to leakage of air. Air velocity measured at the beading = 1.0 – 1.2 m/s.



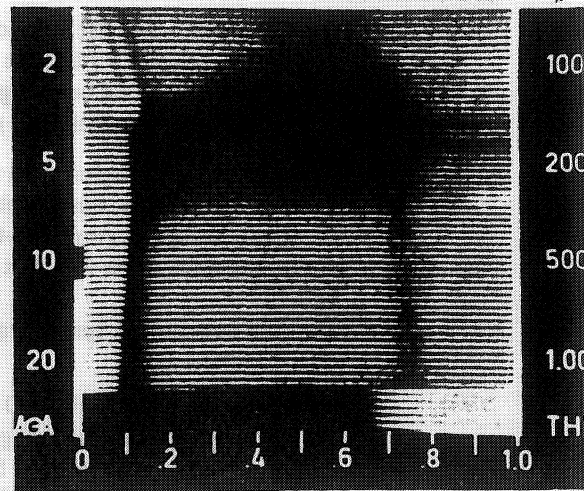
b. Nedkylt ytparti vid takfotsanslutning. Felet beror på luftläckage. Uppmätt lufthastighet vid taklist ca 2 m/s (punktvis). Den tandade konturen på svärtningen framträder tydligt.

b. Cold section at the junction with the eaves. The cause of the defect is air leakage. Air velocity measured at the beading (at isolated points) approx. 2 m/s. The serrated contour of the black portion is plainly visible.



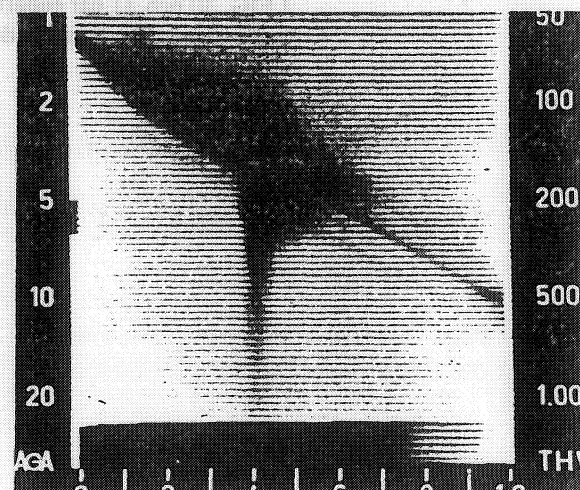
c. Nedkylt ytparti vid takhörn och takfot. Felet beror på luftläckage vid takfotsanslutningen. Uppmätt lufthastighet vid taklist 0,3–0,4 m/s.

c. Cold section at corner of ceiling and the eaves. The defect is due to leakage of air at the junction with the eaves. Air velocity measured at the beading = 0.3–0.4 m/s.



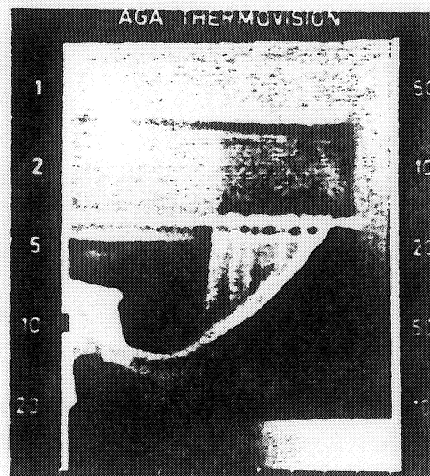
d. Nedkylt ytparti vid takfot och takhörn. Förmodat byggtyp är bristfälligt utförande av isolering i detta parti kombinerat med luftrörelser i isoleringsmaterialet.

d. Cold section at the eaves and corner of the ceiling. Supposed building defect is faulty laying of the insulation in this section, combined with air movements in the insulation material.



e. Nedkylt ytparti vid takfot där regel ansluter. Felet beror på luftläckage. Uppmätt lufthastighet vid taklist ca 2,5 m/s.

e. Cold section at junction between eaves and studs. The defect is caused by leakage of air. Air velocity measured at the beading approx. 2.5 m/s.



f. Väl markerad nedkyld rektangulär yta ovanför fönster vid vägg. Förmodat byggtyp är att delar av isoleringen saknas.

f. Well-defined rectangular cold section above window at the corner of the wall. Supposed building defect is missing insulation.

golvlisten liknande det i termogram *a*. Denna nedkylning är orsakad av luftläckage som uppkommit genom att tätningslisten vid provväggs anslutning mot golvytan borttagits (fel nr 21 enligt FIG. 22).

Slutsats: Då luft rörelse också registrerades vid golvlist i termogram *a* torde felet i detta ytparti vara av typ luftläckage på grund av otäthet vid bjälklagsanslutning (dvs. fel nr 21 enligt FIG. 22).

6.2 Exempel på termogram tagna vid fältmätningar

Avslutningsvis visas i FIG. 30 och 31 ett antal termogram av väggpartier där tydliga byggfel kan urskiljas. Termogrammen är tagna vid fältmätningar utförda under vintersäsongen 1970–71. Avsikten med dessa termogram är att visa exempel på de varierande utseenden som termogrammen kan uppvisa vid olika byggfel. I de fall man ej kunnat verifiera byggfelet genom okulärbesiktning har detta i figurtexten angivits med förmodat byggfel.

I FIG. 30 och 31 har enbart en gråtonsbild använts för att göra en kvalitativ bedömning av isoleringens utförande i yttervägg.

taken at about the same measuring conditions as thermogram *a*. Differences can be found between the thermograms. The section near the skirting board has a different appearance in thermogram *a* than the same section in thermogram *b*. The design drawing cannot provide a reasonable explanation of this discrepancy.

A comparison is made with thermograms of the same section of framed cladding panel No 1 with artificial defects, taken at the same measuring conditions as those applicable to thermogram *b* (Appendix 19).

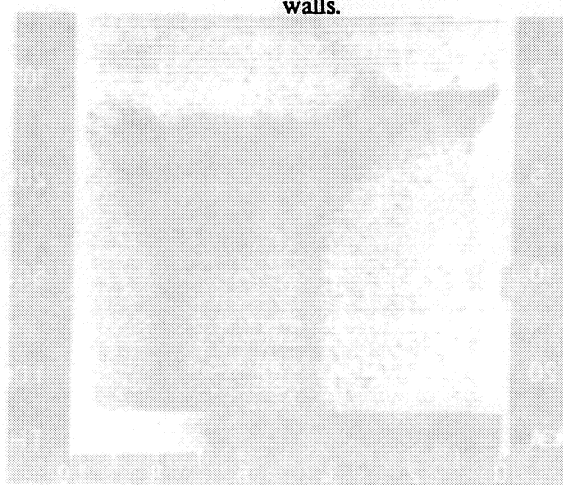
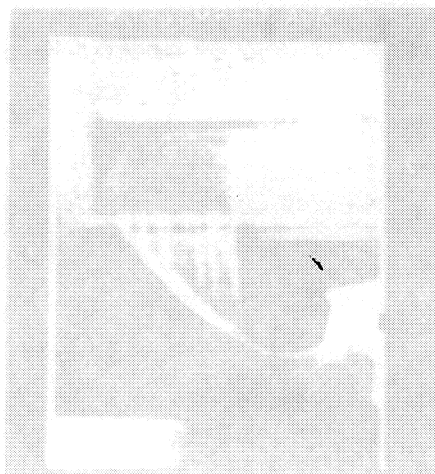
The appearance of the thermogram for the section of the surface near the skirting board is similar to that in thermogram *a*. The cooling-down in this case is due to leakage of air caused by removal of the weatherstrip at the junction of the test wall with the floor surface (Defect No 21 according to FIG. 22).

Conclusion: Since an air movement was also found at the skirting board in thermogram *a*, the defect in this section of the surface is probably of the type due to leakage of air caused by lack of insulation at the junction with the floor (i.e. defect No 21 according to FIG. 22).

6.2 Examples of thermograms taken during field measurements

A number of thermograms of sections of walls in which defects are plainly seen are shown in FIGs. 30 and 31. These thermograms were taken during field measurements in the 1970–71 winter season. The object of showing these thermograms is to demonstrate the variations which may occur in the thermograms relating to different building defects. In cases where the building defect could not be confirmed by opening up the wall and visually inspecting the defect, this has been indicated by using the expression "supposed building defect".

Only one monochrome image has been used in FIGs. 30 and 31 in order to make a qualitative assessment of the construction of the insulation in external walls.



7 Litteratur / Literature

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¹ På svenska med engelsk sammanfattning/ in Swedish with English summary.

² Endast på svenska/ only in Swedish.

Register med typtermogram Catalogue of typical thermograms

1 – 24 Regelvägg nr 1 / Framed cladding panel No. 1

25 – 30 Regelvägg nr 2 / Framed cladding panel No. 2

31 – 42 Sandwichvägg / Sandwich wall unit

43 – 56 Lättbetongvägg / Light concrete wall

-Felfri konstruktion / Correct design

120 mm mineralull / Mineral wool

Temperaturskillnad (inne – ute) /

Difference in temperature (indoors – outdoors): $t_i - t_u = 11^\circ\text{C}$

Tryckskillnad (inne – ute) /

Difference in pressure (indoors – outdoors): $p_i - p_u = 0 \text{ N/m}^2$

A4, B4, C4, D4

vit/white 21.2 – 22.6°C

gul/yellow 19.7 – 21.1°C

röd/red 18.1 – 19.6°C

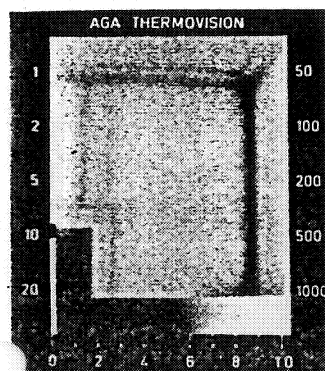
violett/purple 16.4 – 18.1°C

ljusgrön/light green 14.6 – 16.3°C

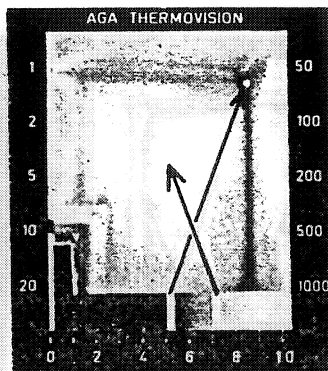
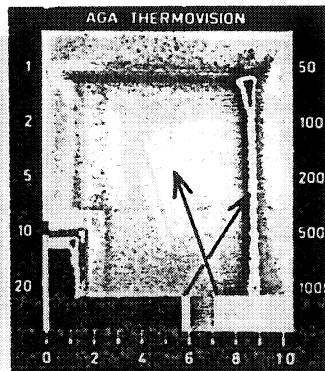
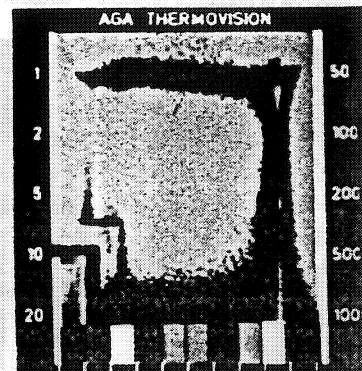
mörkgrön/dark green 12.7 – 14.5°C

ljusblå/light blue 10.7 – 12.6°C

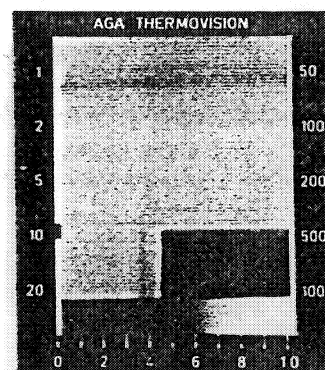
mörkblå/dark blue 8.6 – 10.7°C



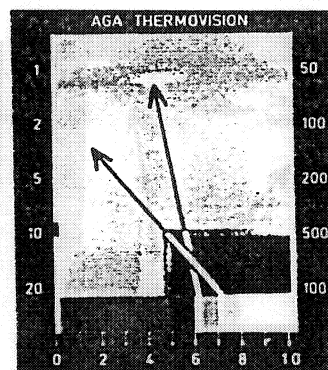
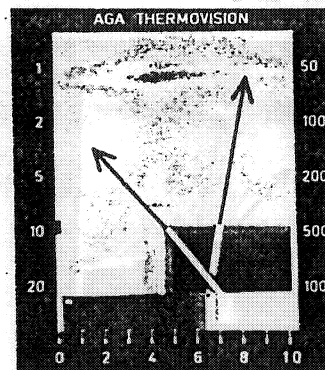
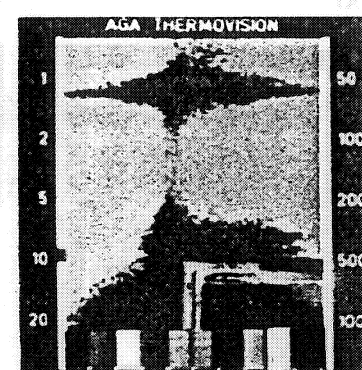
A1

A2 $\Delta t = 3.0^\circ\text{C}$ A3 $\Delta t = 1.8^\circ\text{C}$ 

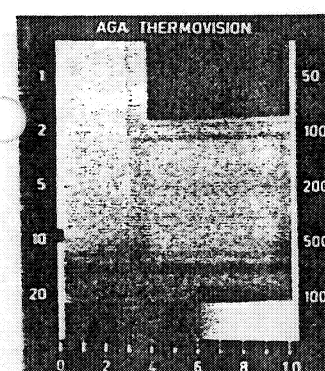
A4



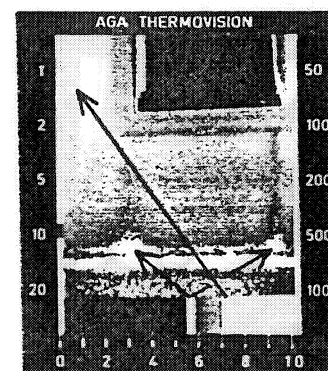
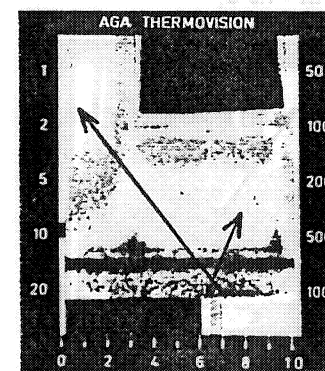
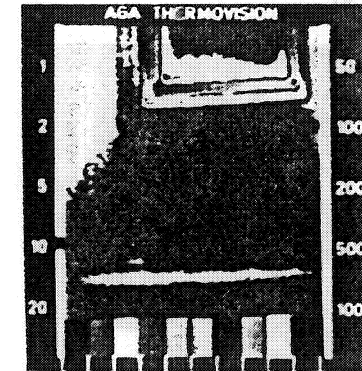
B1

B2 $\Delta t = 1.5^\circ\text{C}$ B3 $\Delta t = 0.9^\circ\text{C}$ 

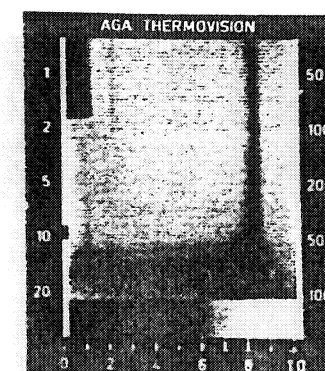
B4



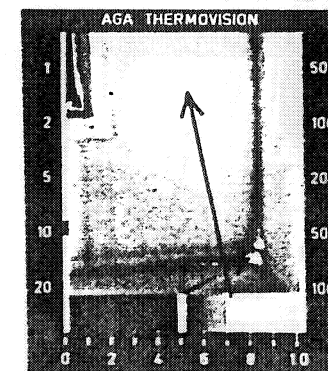
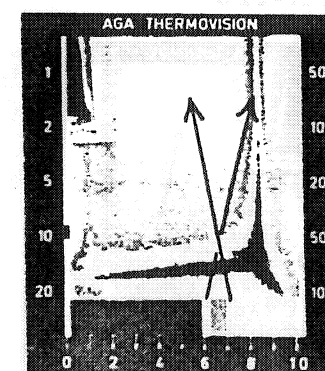
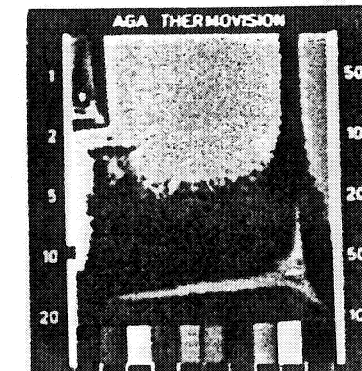
C1

C2 $\Delta t = 2.2^\circ\text{C}$ C3 $\Delta t = 1.4^\circ\text{C}$ 

C4



D1

D2 $\Delta t = 3.3^\circ\text{C}$ D3 $\Delta t = 1.7^\circ\text{C}$ 

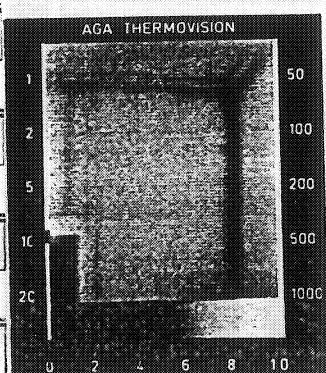
D4

120 mm minerall / Mineral wool

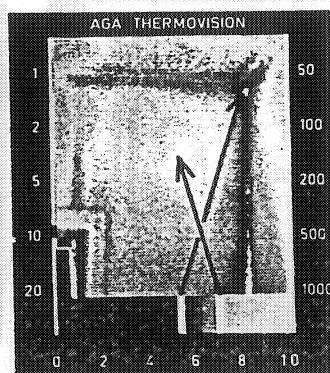
Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 11^\circ\text{C}$

Tryckskillnad (inne – ute) /
Difference in pressure (indoors – outdoors): $p_i - p_u = +50 \text{ N/m}^2$

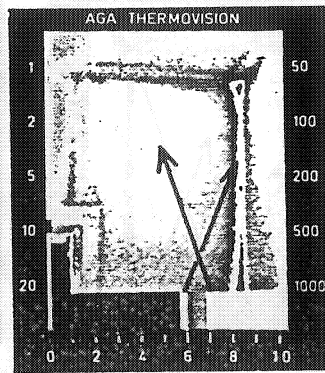
A4, B4, C4, D4	
vit/white	21.2 – 22.6°C
gul/yellow	19.7 – 21.1°C
röd/red	18.1 – 19.6°C
violett/purple	16.4 – 18.1°C
ljusgrön/light green	14.8 – 16.3°C
mörkgrön/dark green	12.7 – 14.5°C
ljusblå/light blue	10.7 – 12.6°C
mörkblå/dark blue	8.6 – 10.7°C



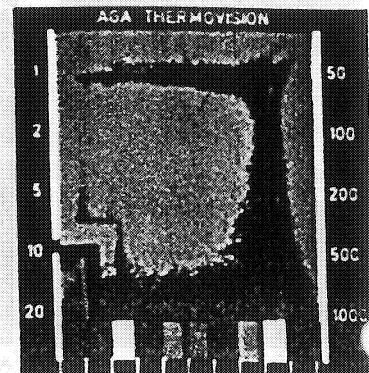
A1



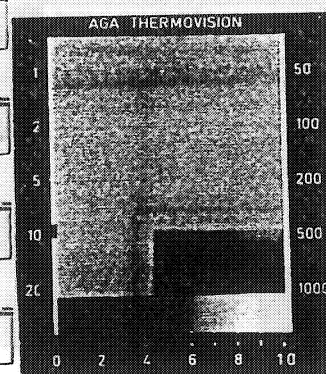
A2 $\Delta t = 2.7^\circ\text{C}$



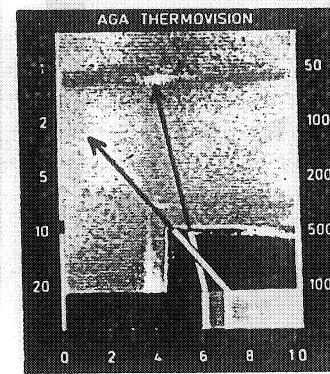
A3 $\Delta t = 1.8^\circ\text{C}$



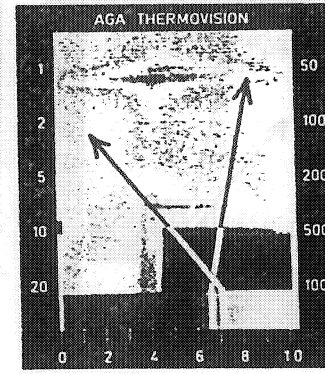
A4



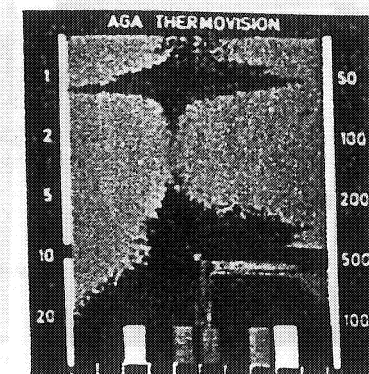
B1



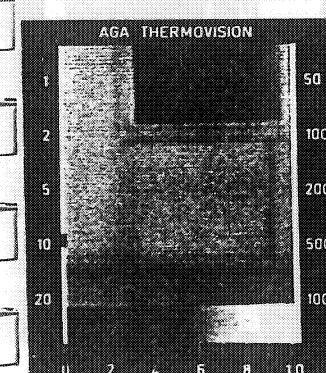
B2 $\Delta t = 1.5^\circ\text{C}$



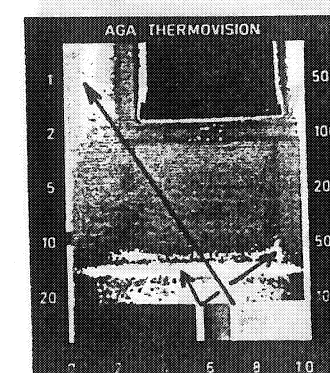
B3 $\Delta t = 0.8^\circ\text{C}$



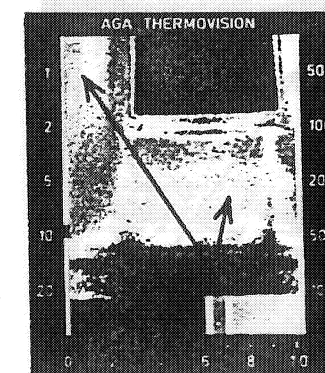
B4



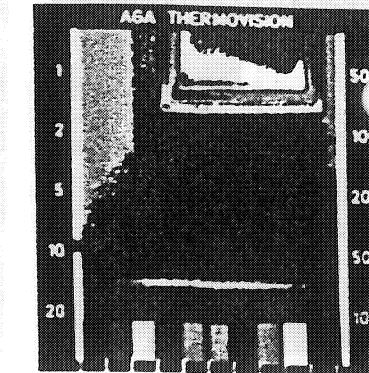
C1



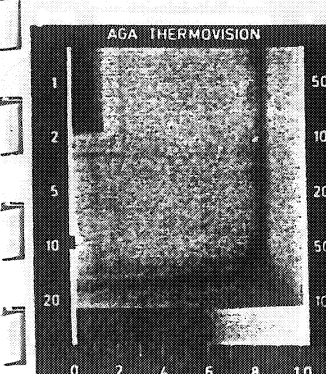
C2 $\Delta t = 2.2^\circ\text{C}$



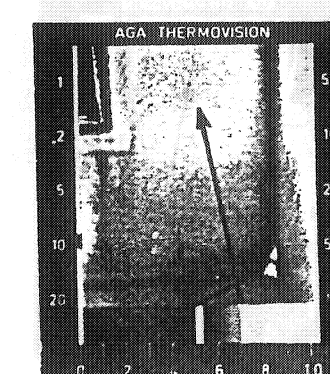
C3 $\Delta t = 1.4^\circ\text{C}$



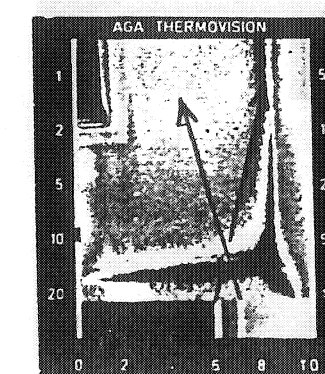
C4



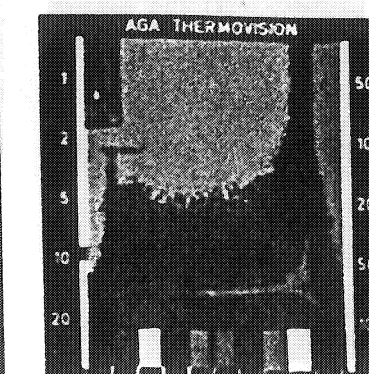
D1



D2 $\Delta t = 3.2^\circ\text{C}$



D3 $\Delta t = 1.6^\circ\text{C}$



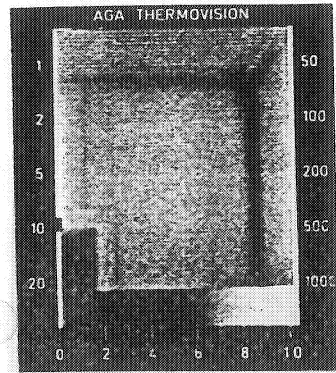
D4

120 mm mineralull / Mineral wool

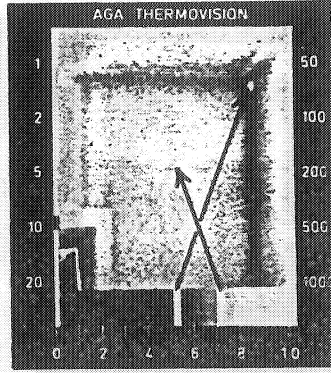
Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 11^\circ\text{C}$

Tryckskillnad (inne – ute) /
Difference in preassure (indoors – outdoors): $p_i - p_u = -50 \text{ N/m}^2$

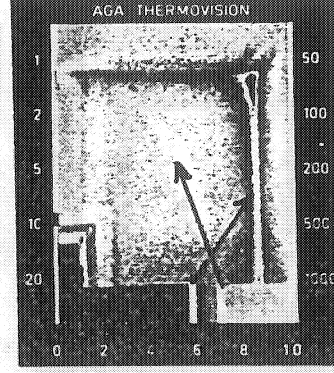
A4, B4, C4, D4	
vit/white	21.2 – 22.8°C
gul/yellow	19.7 – 21.1°C
röd/red	18.1 – 19.6°C
violett/purple	16.4 – 18.1°C
ljusgrön/light green	14.6 – 16.3°C
mörkgrön/dark green	12.7 – 14.5°C
ljusblå/light blue	10.7 – 12.6°C
mörkblå/dark blue	8.8 – 10.7°C



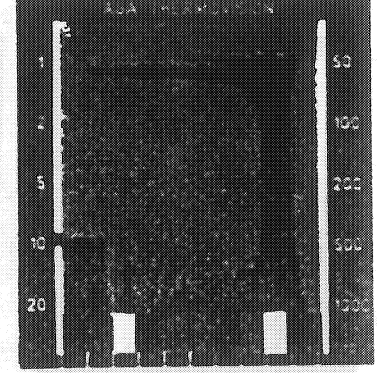
A1



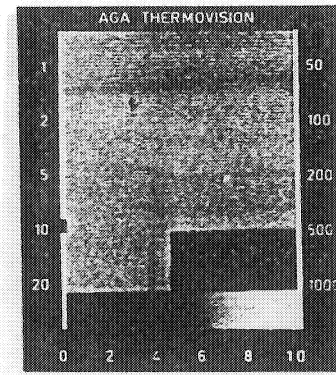
A2 $\Delta t = 2.9^\circ\text{C}$



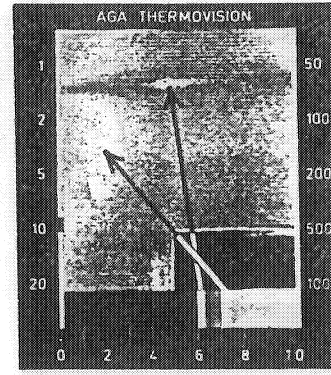
A3 $\Delta t = 1.8^\circ\text{C}$



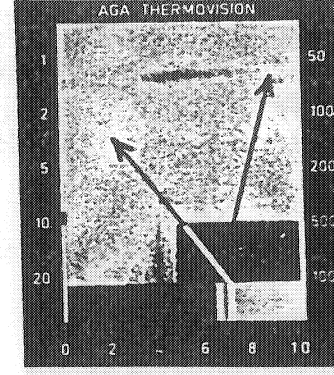
A4



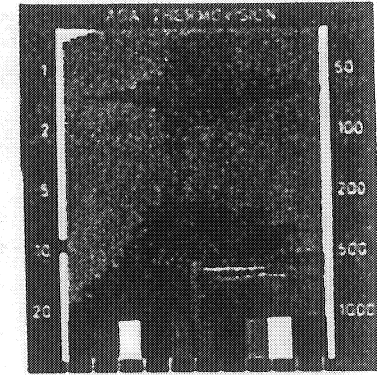
B1



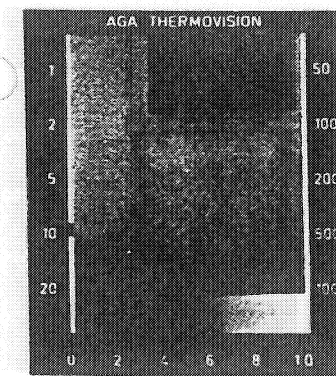
B2 $\Delta t = 1.5^\circ\text{C}$



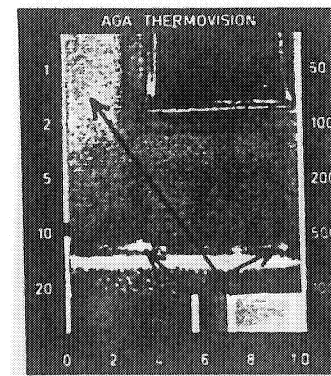
B3 $\Delta t = 0.6^\circ\text{C}$



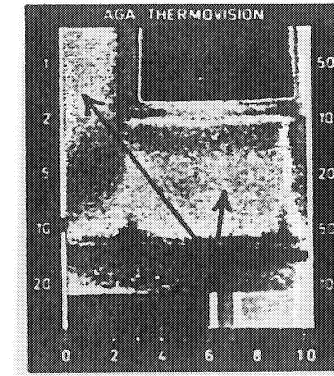
B4



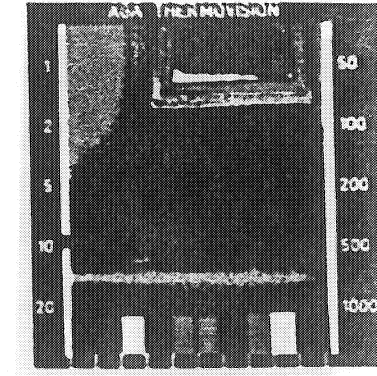
C1



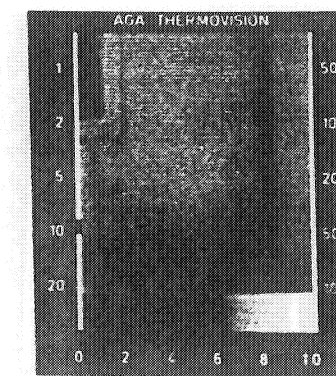
C2 $\Delta t = 2.2^\circ\text{C}$



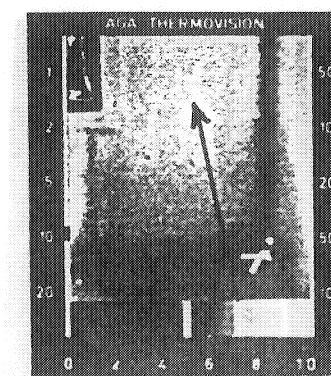
C3 $\Delta t = 1.5^\circ\text{C}$



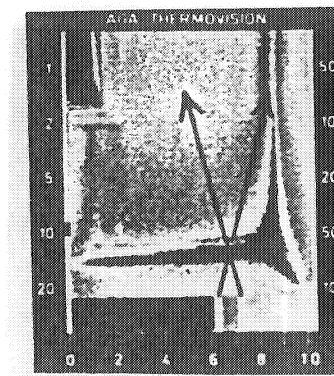
C4



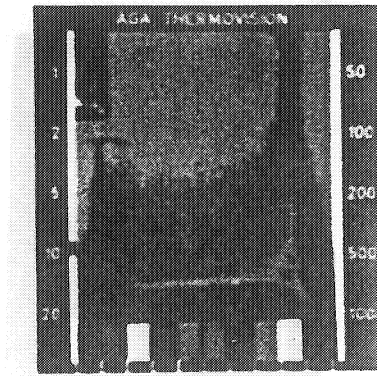
D1



D2 $\Delta t = 3.3^\circ\text{C}$



D3 $\Delta t = 1.5^\circ\text{C}$



D4

Felfri konstruktion / Correct design

-120 mm mineralull / Mineral wool

Temperaturskillnad (inne - ute) /

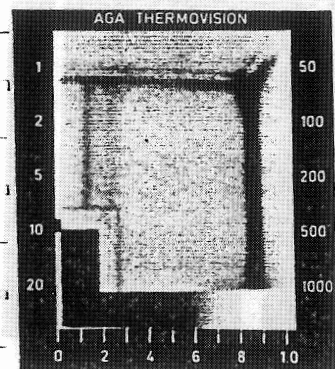
Difference in temperature (indoors - outdoors): $t_i - t_u = 26^\circ\text{C}$

Tryckskillnad (inne - ute) /

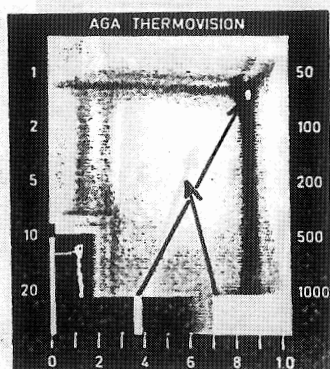
Difference in pressure (indoors - outdoors): $p_i - p_u = 0\text{ N/m}^2$

A4, B4, C4, D4

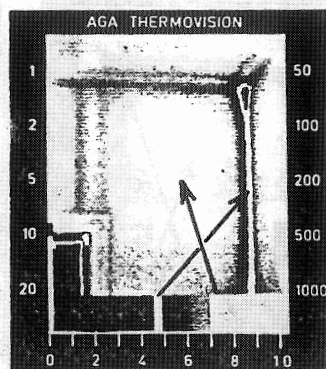
vit/white	20.7 - 22.0°C
gul/yellow	19.1 - 20.6°C
röd/red	17.4 - 19.0°C
violett/purple	15.7 - 17.3°C
ljusgrön/light green	13.8 - 15.6°C
mörkgrön/dark green	11.9 - 13.7°C
ljusblå/light blue	9.9 - 11.8°C
mörkblå/dark blue	7.8 - 9.8°C



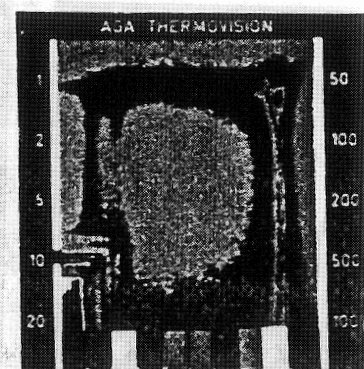
A1



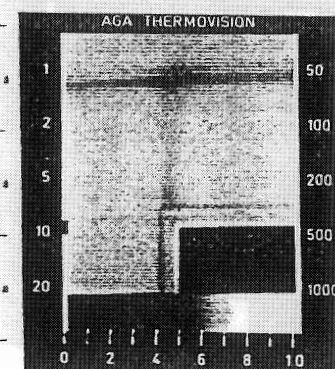
A2 $\Delta t = 5.7^\circ\text{C}$



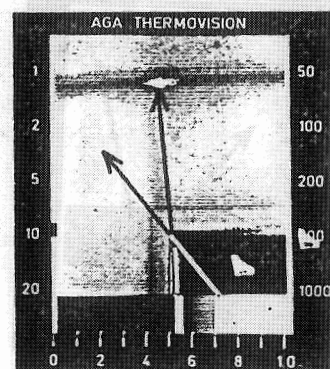
A3 $\Delta t = 3.8^\circ\text{C}$



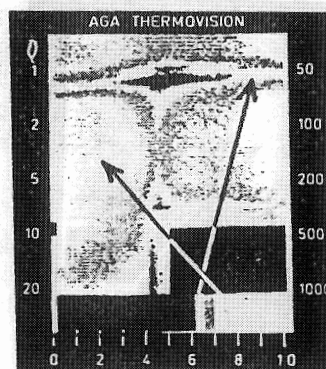
A4



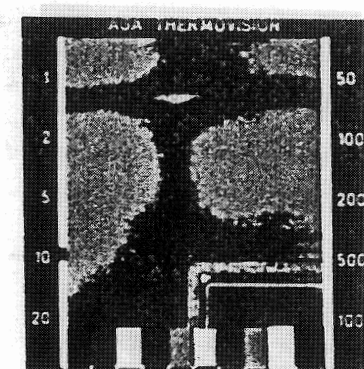
B1



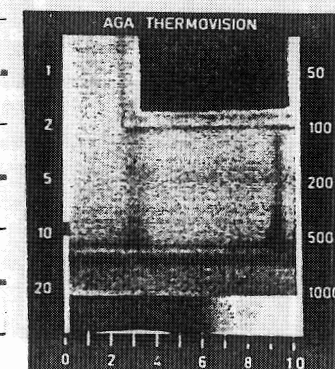
B2 $\Delta t = 2.7^\circ\text{C}$



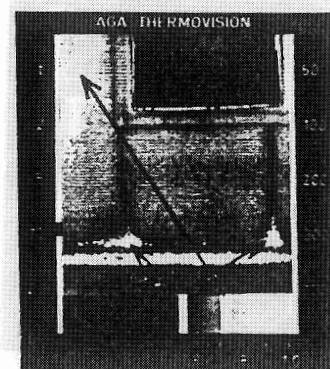
B3 $\Delta t = 1.4^\circ\text{C}$



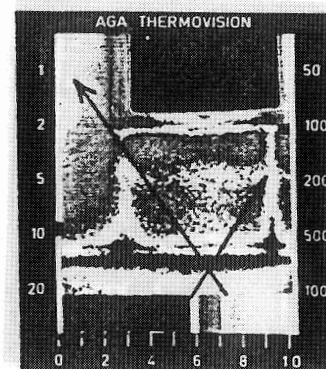
B4



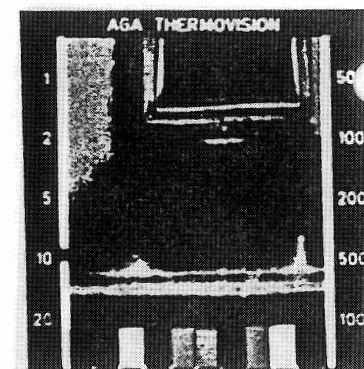
C1



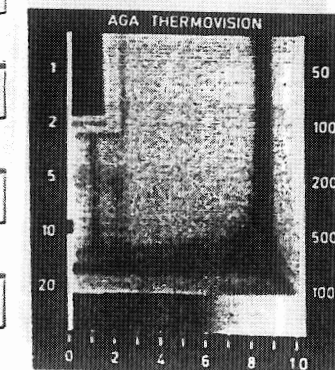
C2 $\Delta t = 2.9^\circ\text{C}$



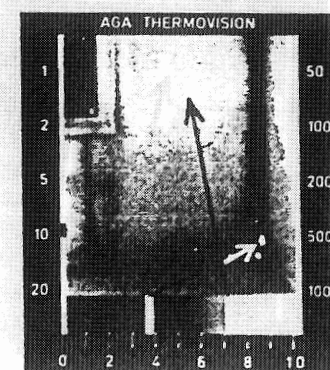
C3 $\Delta t = 1.9^\circ\text{C}$



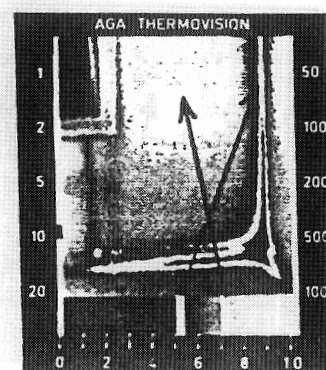
C4



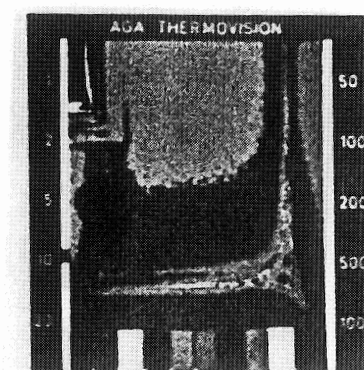
D1



D2 $\Delta t = 5.7^\circ\text{C}$



D3 $\Delta t = 3.1^\circ\text{C}$



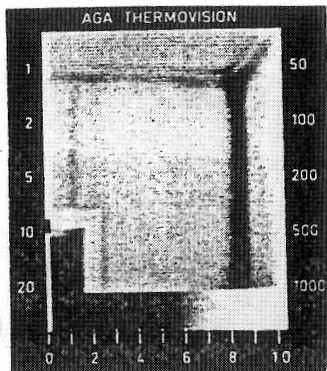
D4

120 mm mineralull / Mineral wool

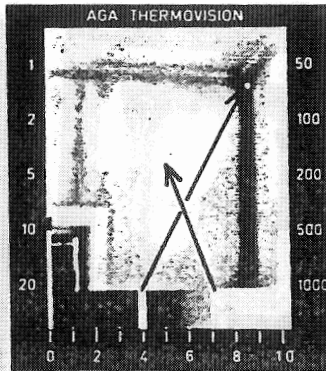
Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 26^\circ\text{C}$

Tryckskillnad (inne – ute) /
Difference in pressure (indoors – outdoors): $p_i - p_u = +50 \text{ N/m}^2$

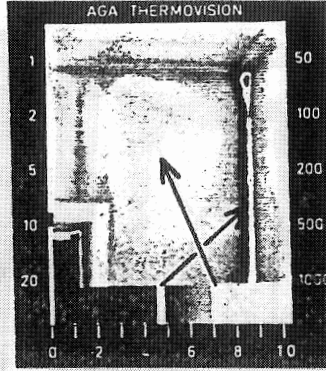
A4, B4, C4, D4	
vit/white	20.7 – 22.0°C
gul/yellow	19.1 – 20.6°C
röd/red	17.4 – 19.0°C
violett/purple	15.7 – 17.3°C
ljusgrön/light green	13.8 – 15.6°C
mörkgrön/dark green	11.9 – 13.7°C
ljusblå/light blue	9.9 – 11.8°C
mörkblå/dark blue	7.8 – 9.8°C



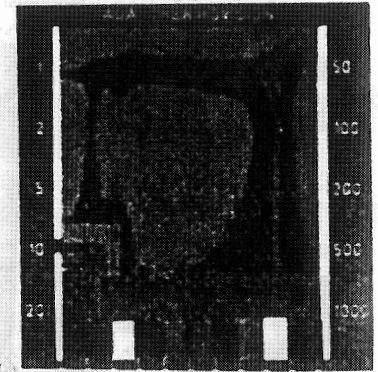
A1



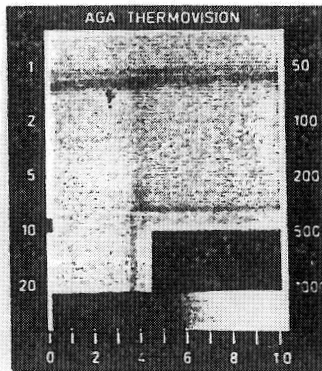
A2 $\Delta t = 5.1^\circ\text{C}$



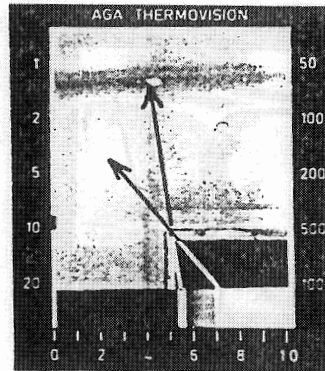
A3 $\Delta t = 3.7^\circ\text{C}$



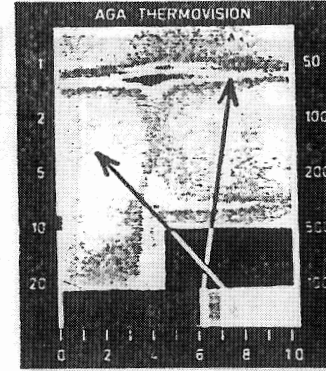
A4



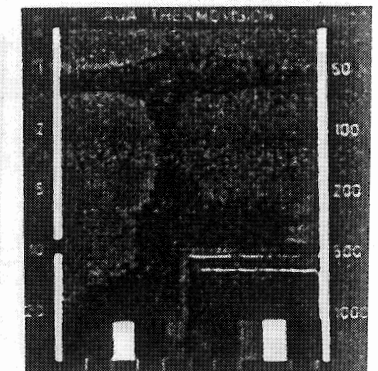
B1



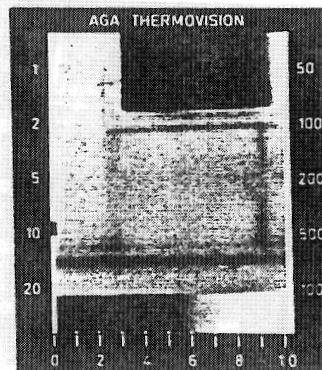
B2 $\Delta t = 2.8^\circ\text{C}$



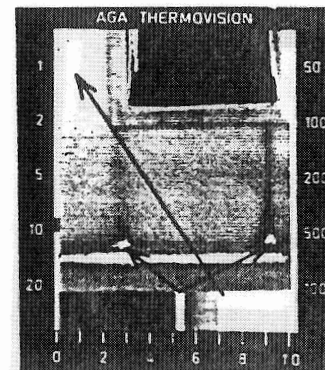
B3 $\Delta t = 1.4^\circ\text{C}$



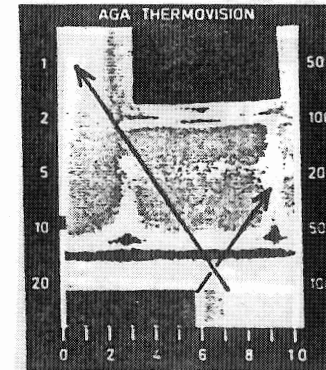
B4



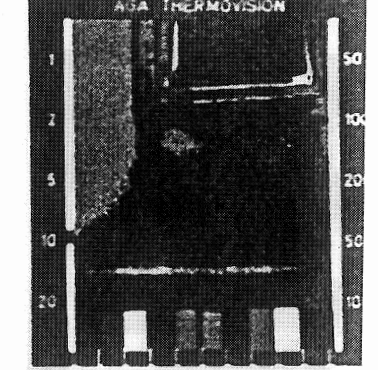
C1



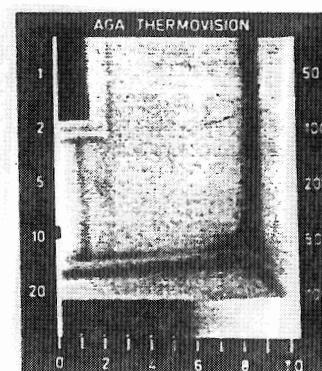
C2 $\Delta t = 2.9^\circ\text{C}$



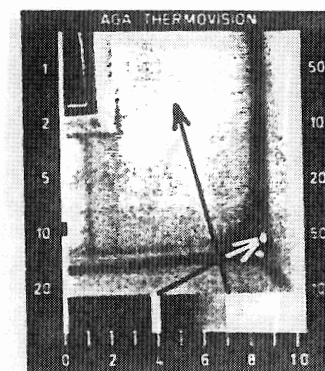
C3 $\Delta t = 1.8^\circ\text{C}$



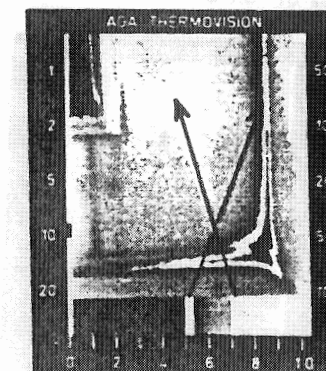
C4



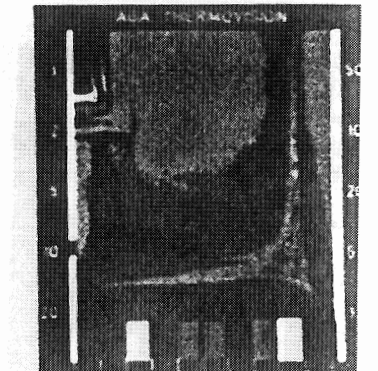
D1



D2 $\Delta t = 5.3^\circ\text{C}$



D3 $\Delta t = 3.2^\circ\text{C}$



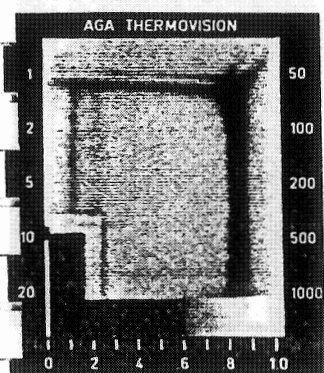
D4

20 mm mineralull / Mineral wool

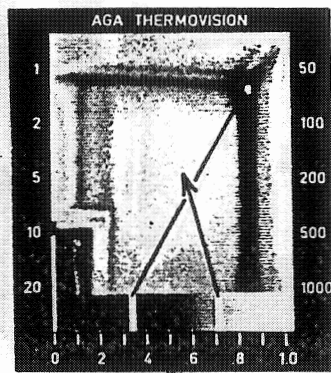
Temperaturskillnad (inne – ute) /
 Difference in temperature (indoors – outdoors): $t_i - t_u = 26^\circ\text{C}$

Tryckskillnad (inne – ute) /
 Difference in pressure (indoors – outdoors): $P_i - P_u = -50 \text{ N/m}^2$

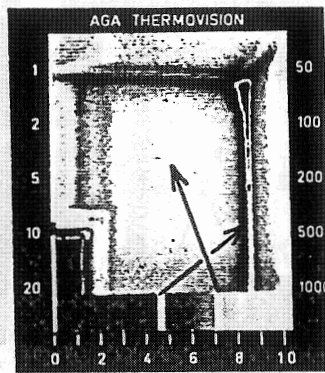
A4, B4, C4, D4	
vit/white	20.7 – 22.0°C
gul/yellow	19.1 – 20.6°C
röd/red	17.4 – 19.0°C
violett/purple	15.7 – 17.3°C
ljusgrön/light green	13.8 – 15.6°C
mörkgrön/dark green	11.9 – 13.7°C
ljusblå/light blue	9.9 – 11.8°C
mörkblå/dark blue	7.8 – 9.8°C



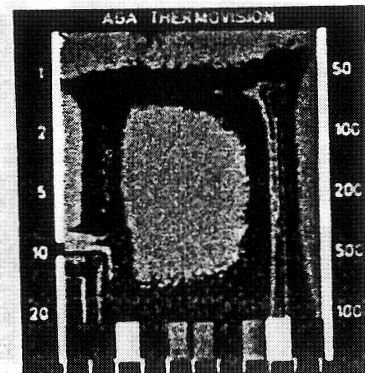
A1



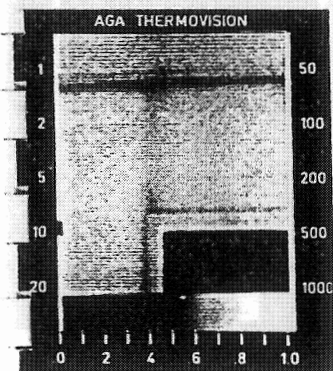
A2 $\Delta t = 6.2^\circ\text{C}$



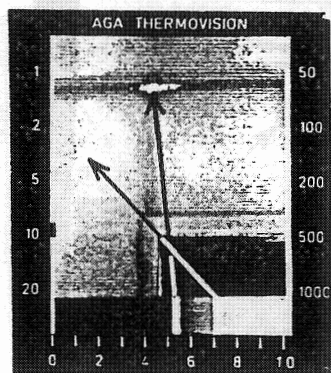
A3 $\Delta t = 3.8^\circ\text{C}$



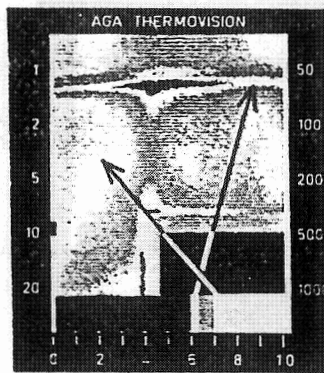
A4



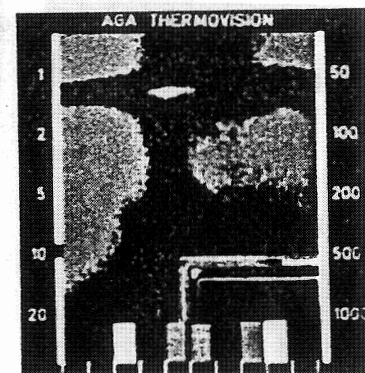
B1



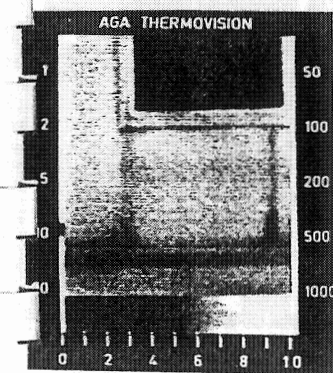
B2 $\Delta t = 2.7^\circ\text{C}$



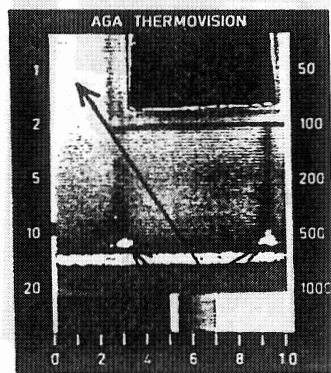
B3 $\Delta t = 1.5^\circ\text{C}$



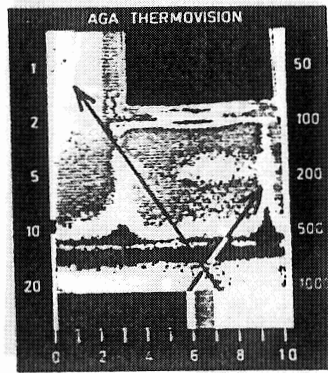
B4



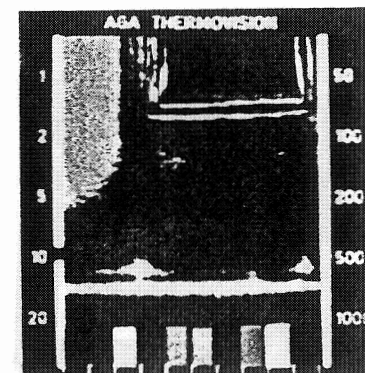
C1



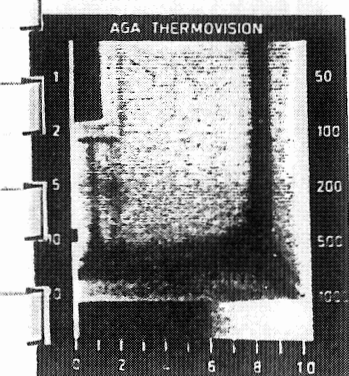
C2 $\Delta t = 3.1^\circ\text{C}$



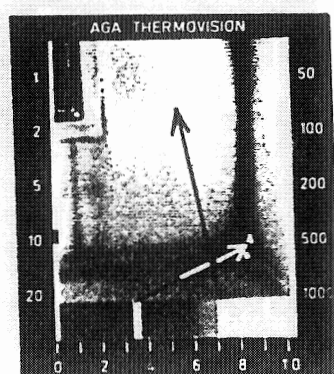
C3 $\Delta t = 1.8^\circ\text{C}$



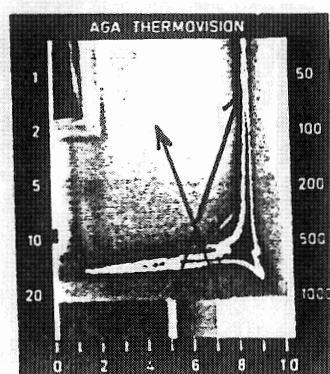
C4



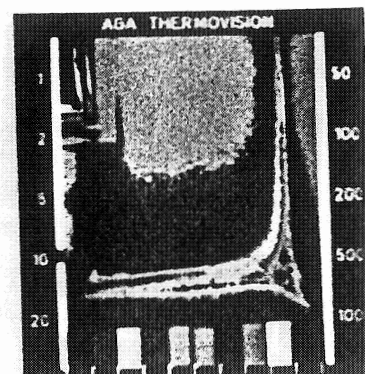
D1



D2 $\Delta t = 6.1^\circ\text{C}$



D3 $\Delta t = 3.3^\circ\text{C}$



D4

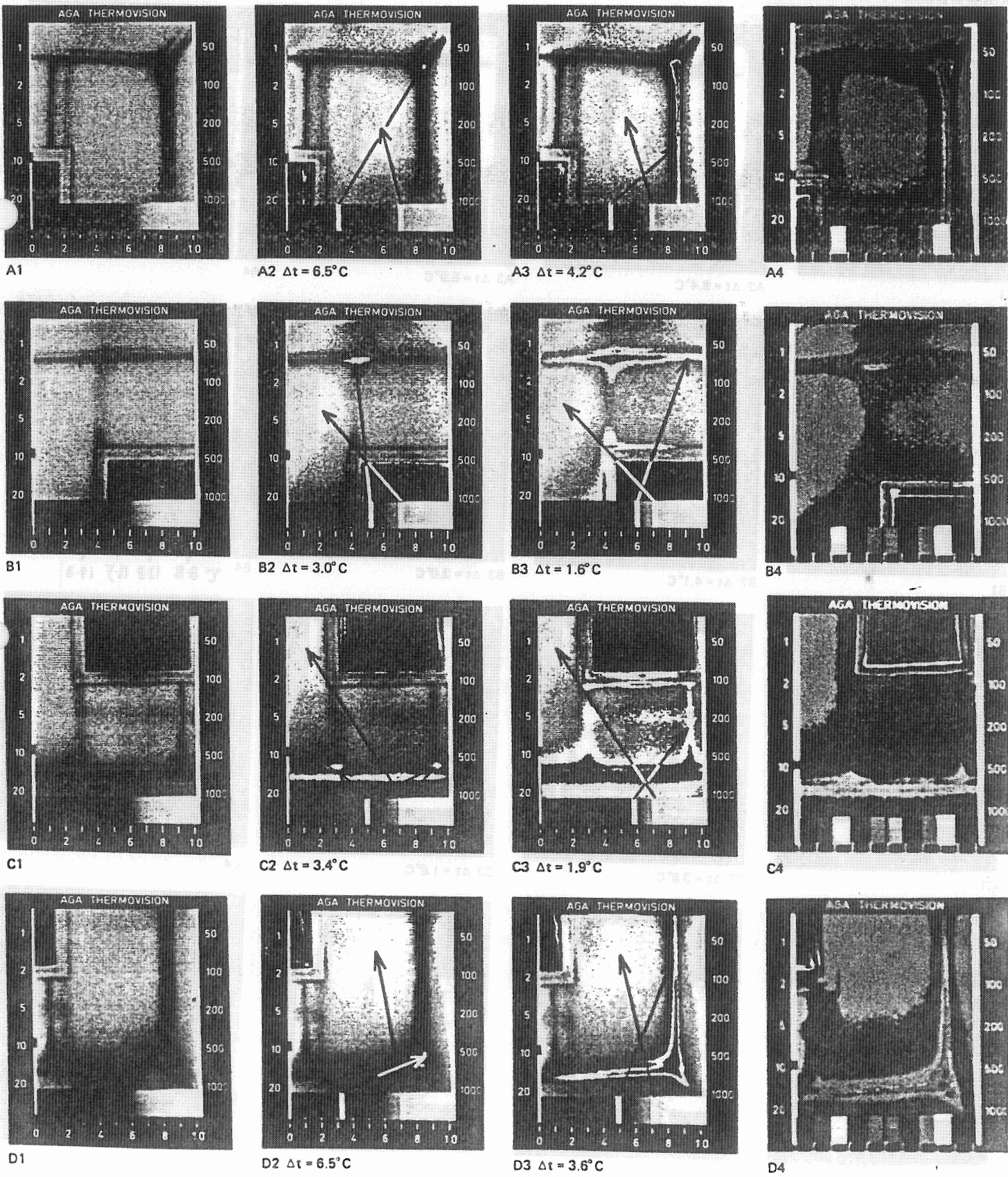
Regelvägg nr 1 / Framed cladding panel No. 1
 Felfri konstruktion / Correct design

120 mm mineralull / Mineral wool

Temperaturskillnad (inne – ute) /
 Difference in temperature (indoors – outdoors): $t_i - t_u = 26^\circ\text{C}$

Tryckskillnad (inne – ute) /
 Difference in pressure (indoors – outdoors): $p_i - p_u = -100\text{ N/m}^2$

A4, B4, C4, D4	
vit/white	20.7 – 22.0°C
gul/yellow	19.1 – 20.6°C
röd/red	17.4 – 19.0°C
violett/purple	15.7 – 17.3°C
ljusgrön/light green	13.8 – 15.6°C
mörkgrön/dark green	11.9 – 13.7°C
ljusblå/light blue	9.9 – 11.8°C
mörkblå/dark blue	7.8 – 9.8°C



Regelvägg nr 1 / Framed cladding panel No. 1
 ölfri konstruktion / Correct design

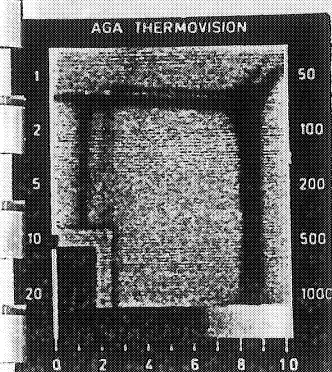
BILAGA / APPENDIX 8

10 mm mineralull / Mineral wool

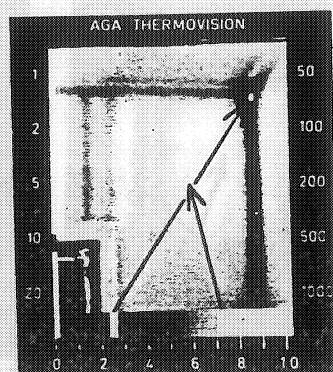
Temperaturskillnad (inne – ute) /
 Difference in temperature (indoors – outdoors): $t_i - t_u = 41^\circ\text{C}$

Tryckskillnad (inne – ute) /
 Difference in pressure (indoors – outdoors): $p_i - p_u = 0 \text{ N/m}^2$

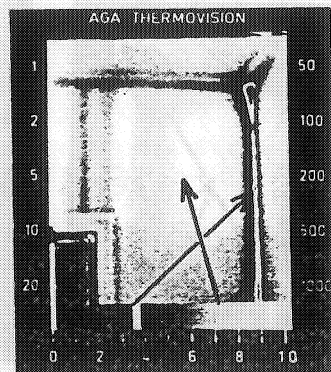
A4, B4, C4, D4	
vit/white	19.8 – 21.3°C
gul/yellow	18.2 – 19.7°C
röd/red	16.5 – 18.1°C
violett/purple	14.8 – 16.4°C
ljusgrön/light green	12.9 – 14.7°C
mörkgrön/dark green	10.9 – 12.8°C
ljusblå/light blue	8.8 – 10.8°C
mörkblå/dark blue	6.6 – 8.7°C



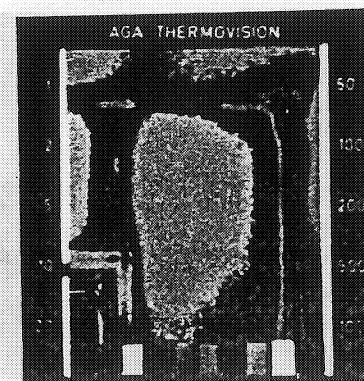
A1



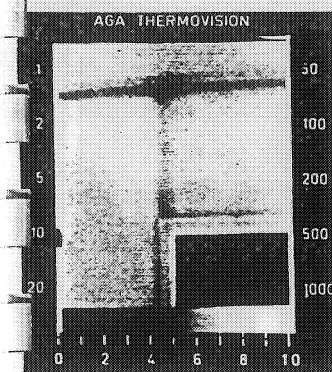
A2 $\Delta t = 8.4^\circ\text{C}$



A3 $\Delta t = 5.9^\circ\text{C}$



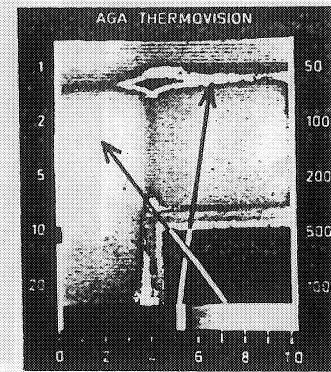
A4



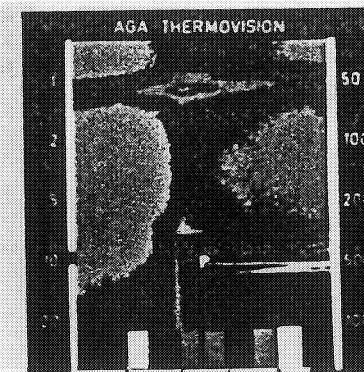
B1



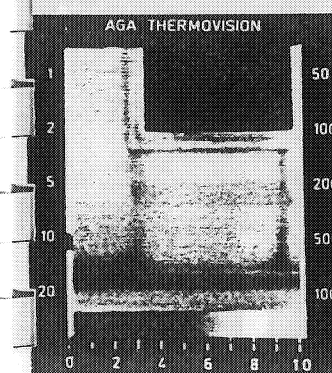
B2 $\Delta t = 4.1^\circ\text{C}$



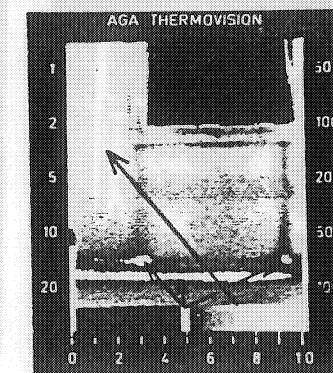
B3 $\Delta t = 3.0^\circ\text{C}$



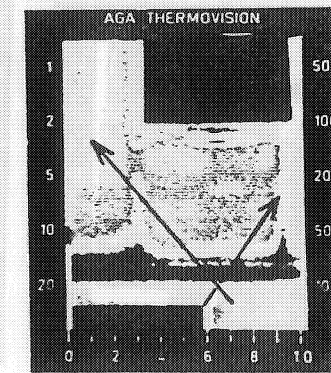
B4 $^\circ\text{C}$ 8-8 12-8 16-5 19-8



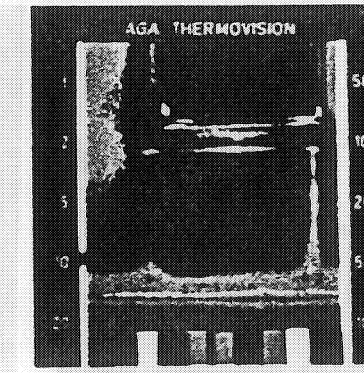
C1



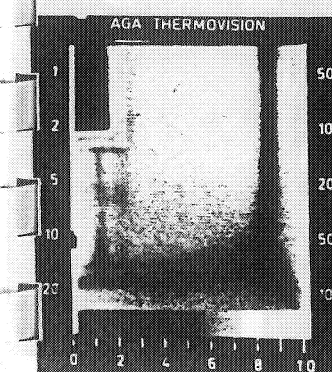
C2 $\Delta t = 3.8^\circ\text{C}$



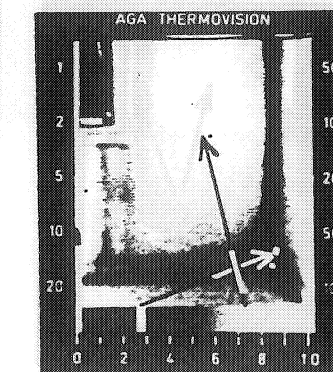
C3 $\Delta t = 1.8^\circ\text{C}$



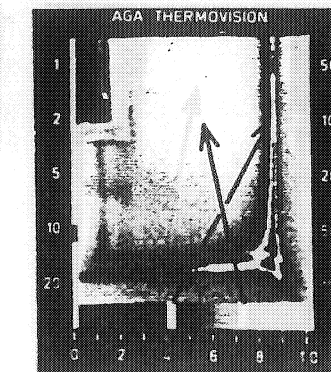
C4



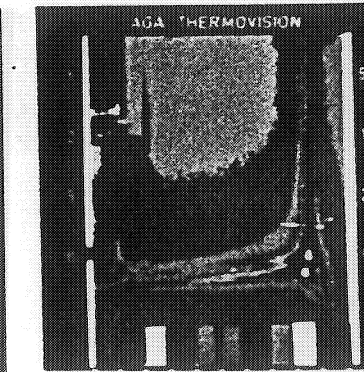
D1



D2 $\Delta t = 7.9^\circ\text{C}$



D3 $\Delta t = 5.2^\circ\text{C}$



D4

Regelvägg nr 1 / Framed cladding panel No. 1
Felfri konstruktion / Correct design

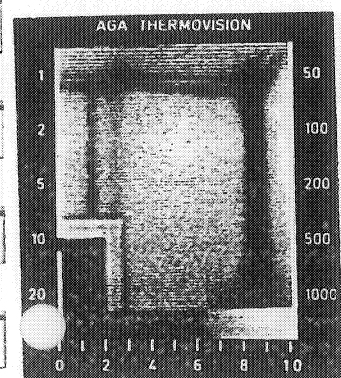
BILAGA / APPENDIX 9

120 mm mineralull / Mineral wool

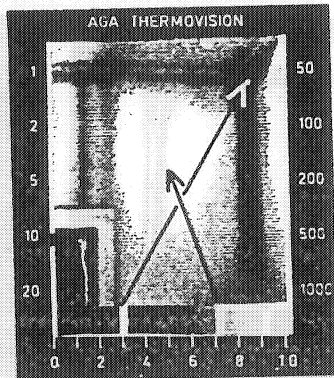
Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 41^\circ\text{C}$

Tryckskillnad (inne – ute) /
Difference in pressure (indoors – outdoors): $p_i - p_u = +50 \text{ N/m}^2$

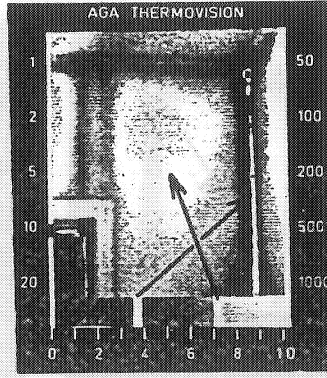
A4, B4, C4, D4	
vit/white	19.8 – 21.3°C
gul/yellow	18.2 – 19.7°C
röd/red	16.5 – 18.1°C
violett/purple	14.8 – 16.4°C
ljusgrön/light green	12.9 – 14.7°C
mörkgrön/dark green	10.9 – 12.8°C
ljusblå/light blue	8.8 – 10.8°C
mörkblå/dark blue	6.6 – 8.7°C



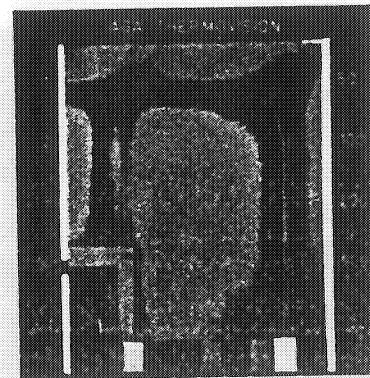
A1



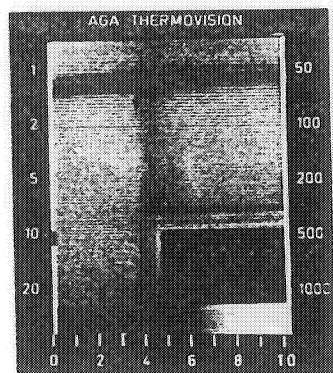
A2 $\Delta t = 7.3^\circ\text{C}$



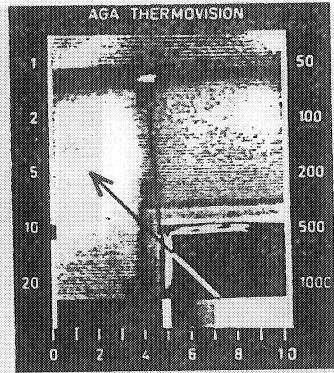
A3 $\Delta t = 5.7^\circ\text{C}$



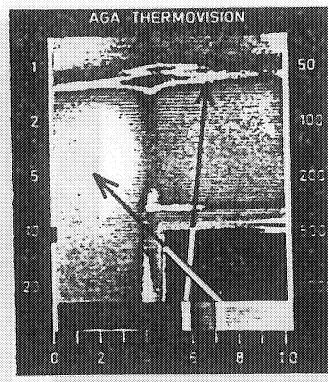
A4



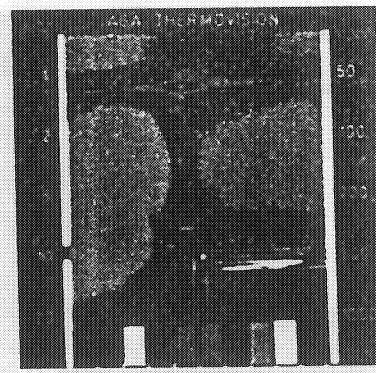
B1



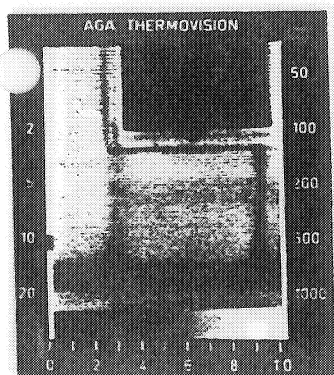
B2 $\Delta t = 3.7^\circ\text{C}$



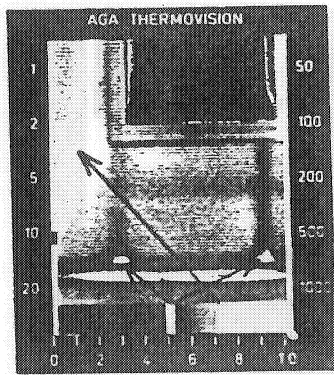
B3 $\Delta t = 2.3^\circ\text{C}$



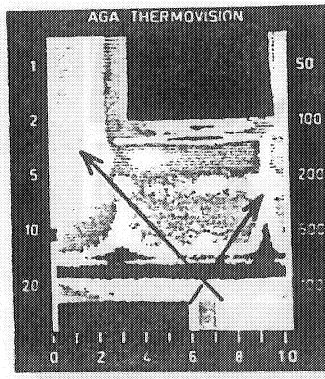
B4



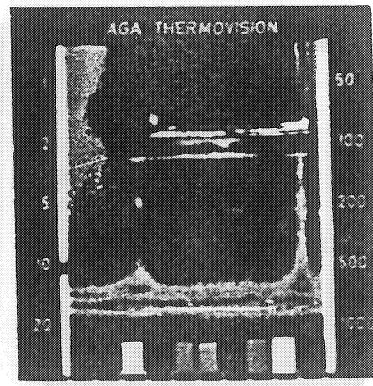
C1



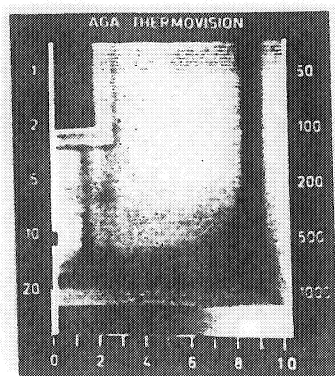
C2 $\Delta t = 3.5^\circ\text{C}$



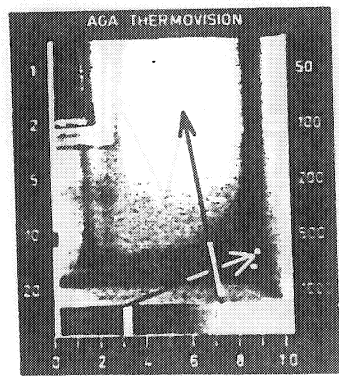
C3 $\Delta t = 1.8^\circ\text{C}$



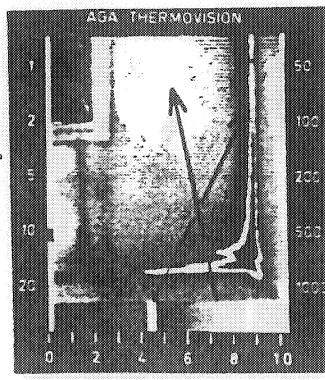
C4



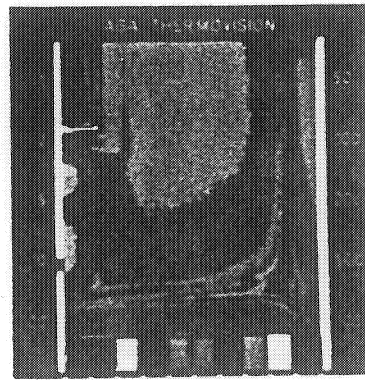
D1



D2 $\Delta t = 7.3^\circ\text{C}$



D3 $\Delta t = 5.2^\circ\text{C}$



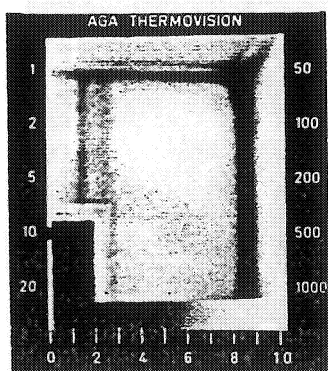
D4

120 mm mineralull / Mineral wool

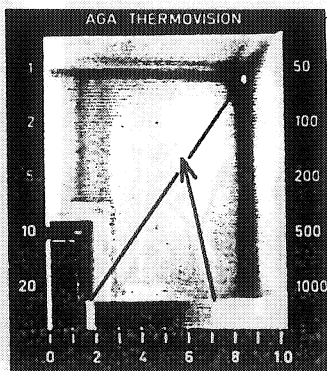
Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 41^\circ\text{C}$

Tryckskillnad (inne – ute) /
Difference in preasure (indoors – outdoors): $p_i - p_u = -50 \text{ N/m}^2$

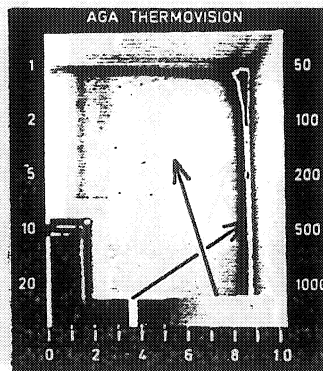
A4, B4, C4, D4	
vit/white	19.8 – 21.3°C
gul/yellow	18.2 – 19.7°C
röd/red	16.5 – 18.1°C
violett/purple	14.8 – 16.4°C
ljusgrön/light green	12.9 – 14.7°C
mörkgrön/dark green	10.9 – 12.8°C
ljusblå/light blue	8.8 – 10.8°C
mörkblå/dark blue	6.6 – 8.7°C



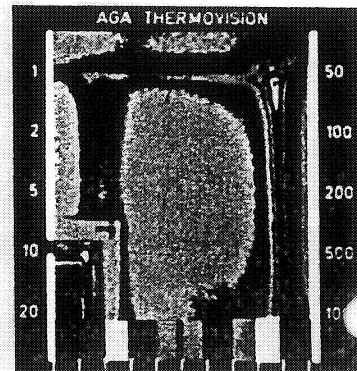
A1



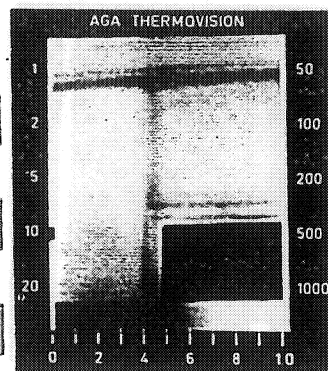
A2 $\Delta t = 9.7^\circ\text{C}$



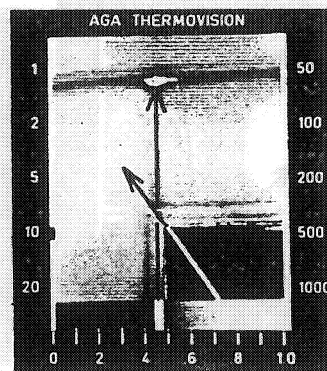
A3 $\Delta t = 5.9^\circ\text{C}$



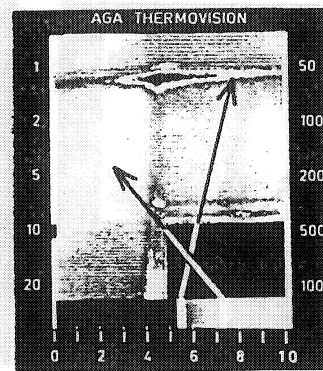
A4



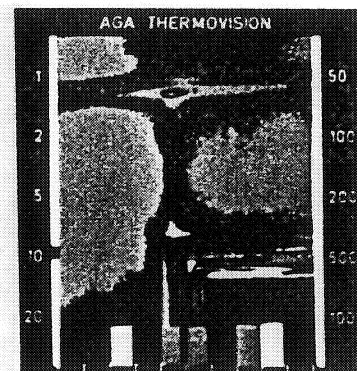
B1



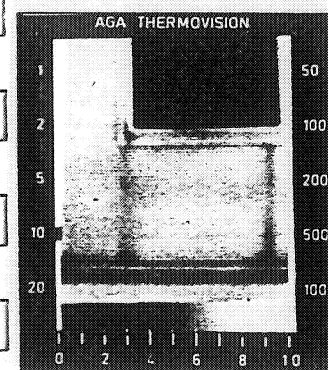
B2 $\Delta t = 4.1^\circ\text{C}$



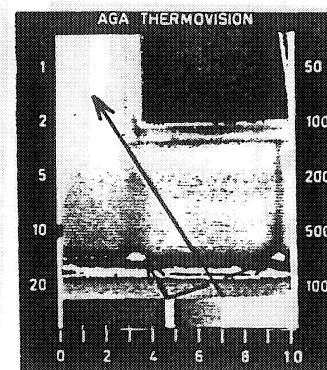
B3 $\Delta t = 2.7^\circ\text{C}$



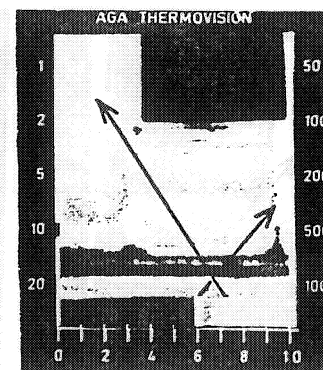
B4



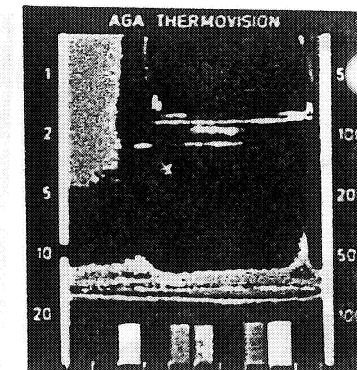
C1



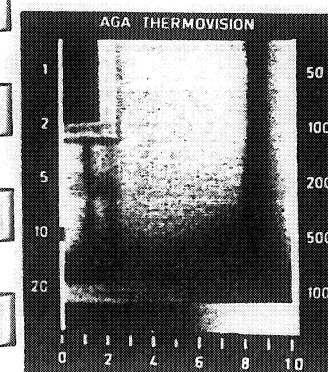
C2 $\Delta t = 4.0^\circ\text{C}$



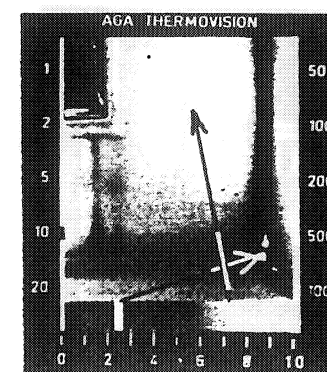
C3 $\Delta t = 1.7^\circ\text{C}$



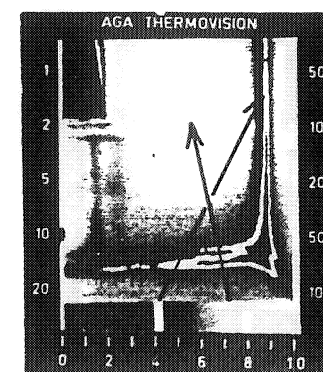
C4



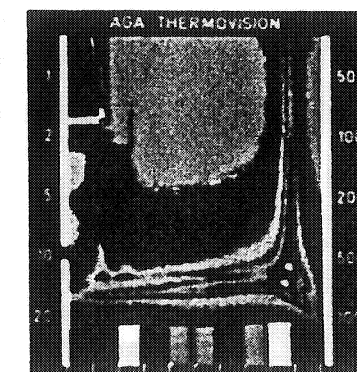
D1



D2 $\Delta t = 8.4^\circ\text{C}$



D3 $\Delta t = 5.2^\circ\text{C}$



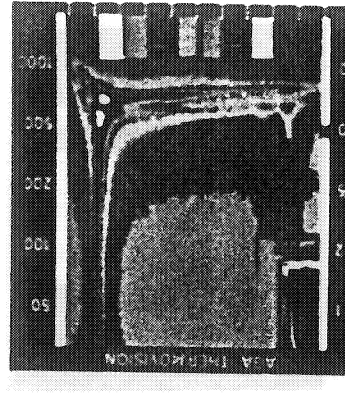
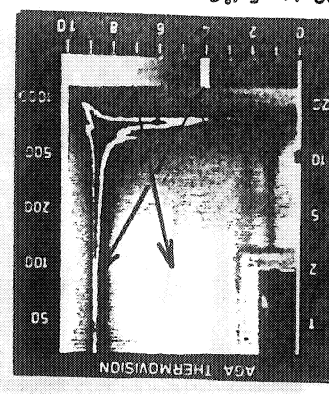
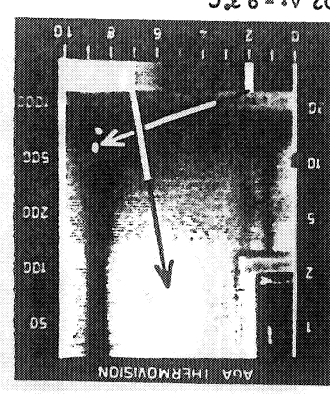
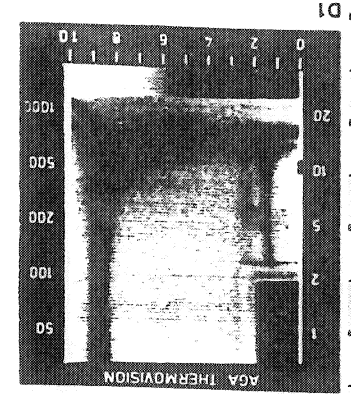
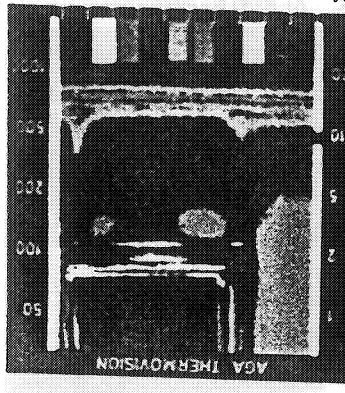
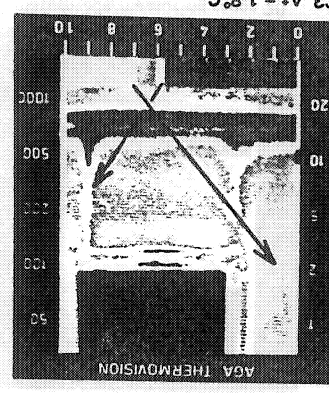
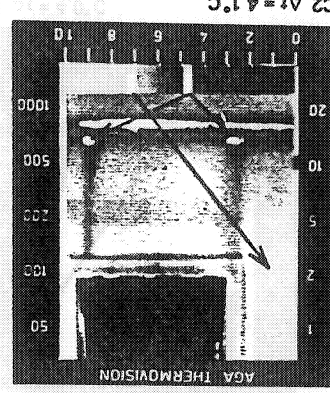
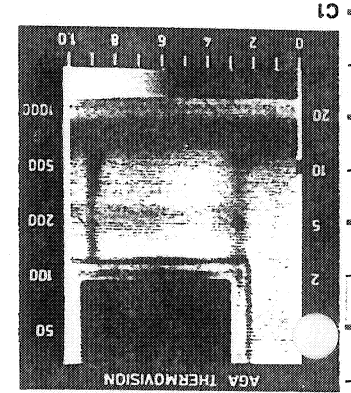
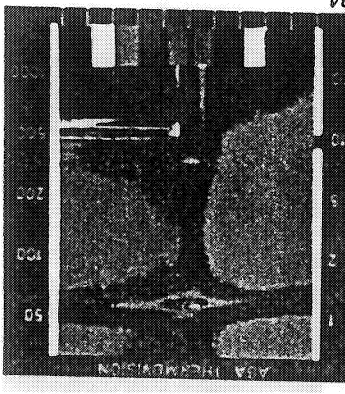
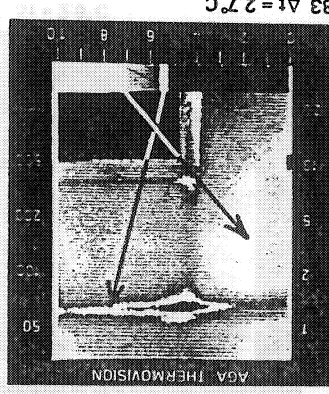
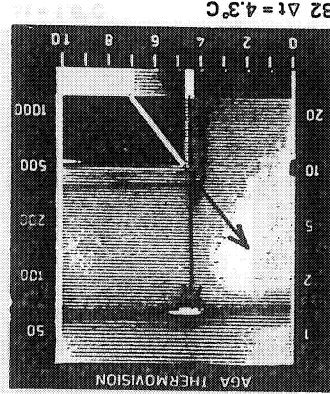
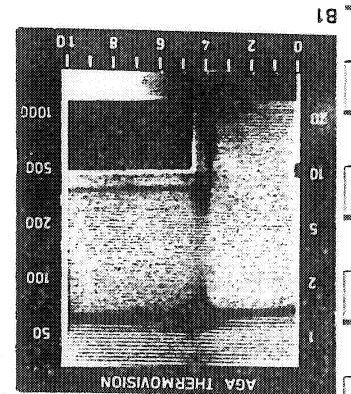
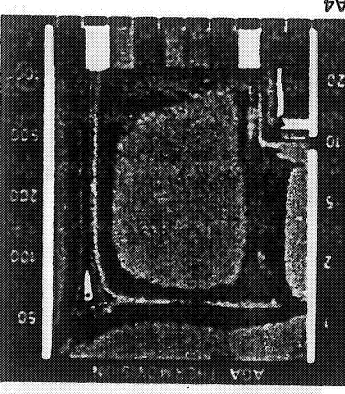
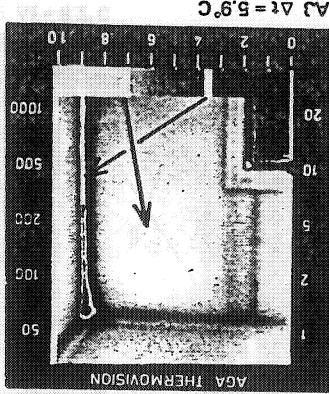
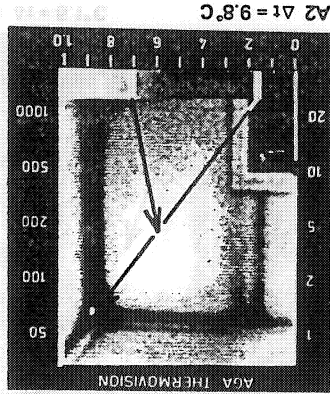
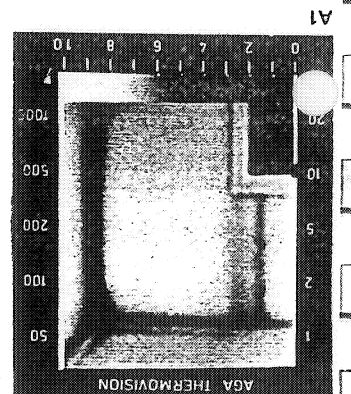
D4

120 mm mineralull / Mineral wool

Temperaturskillnad (inne – ute) /

Difference in temperature (indoors – outdoors): $t_i - t_u = 41^\circ\text{C}$

Tryckskillnad (ute – inne)
Difference in pressure (indoors – outdoors): $p_i - p_u = -100 \text{ N/m}^2$



A4, B4, C4, D4

vit/white

gul/yellow

18.2 – 19.7°C

16.5 – 18.1°C

röd/red

14.8 – 16.4°C

violett/purple

12.9 – 14.7°C

ljusgrön/light green

10.9 – 12.8°C

mörkgrön/dark green

8.8 – 10.8°C

ljusblå/light blue

6.8 – 8.7°C

mörkblå/dark blue

Regelvägg nr 1 / Framed cladding panel No. 1
Felfri konstruktion / Correct design

BILAGA / APPENDIX 12

120 mm mineralull / Mineral wool

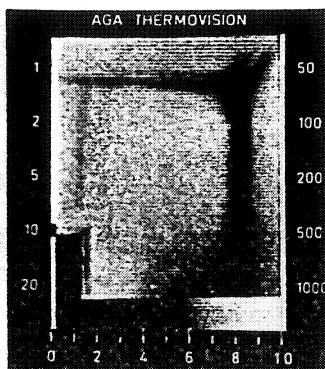
Elradiator med effekten 300 W inkopplad / Electric radiator of 300 W rating switched on

Temperaturskillnad (inne – ute) /

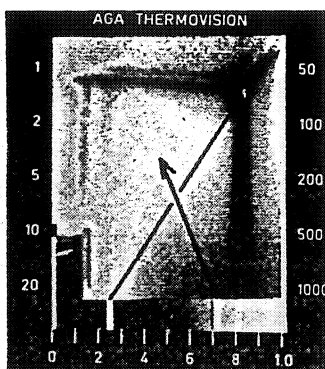
Difference in temperature (indoors – outdoors): $t_i - t_u = 41^\circ\text{C}$

Tryckskillnad (inne – ute) /

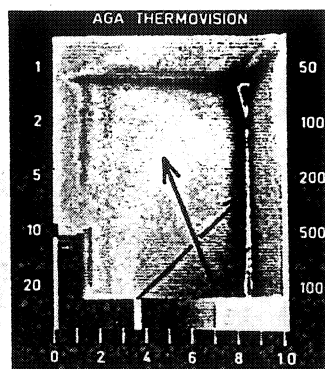
Difference in pressure (indoors – outdoors): $p_i - p_u = 0 \text{ N/m}^2$



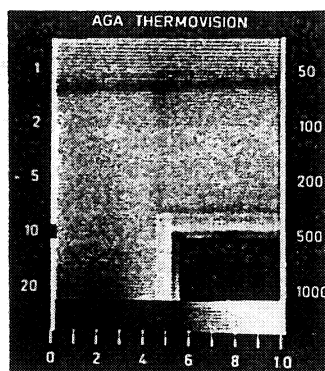
A1



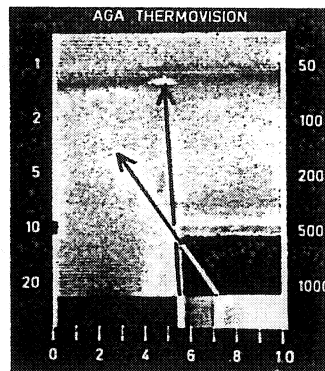
A2 $\Delta t = 8.2^\circ\text{C}$



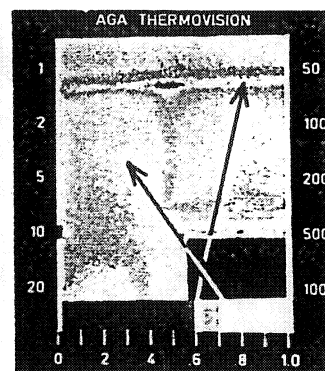
A3 $\Delta t = 6.1^\circ\text{C}$



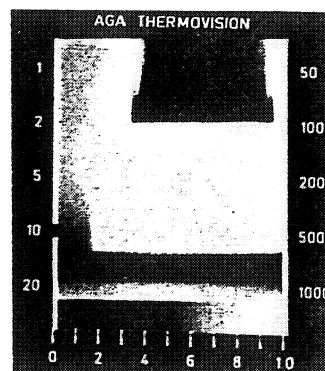
B1



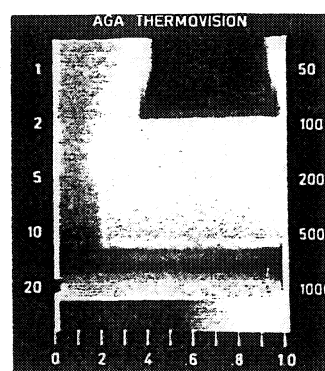
B2 $\Delta t = 2.6^\circ\text{C}$



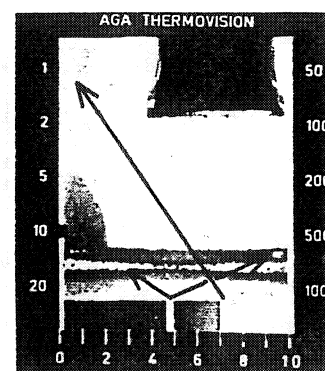
B3 $\Delta t = 1.6^\circ\text{C}$



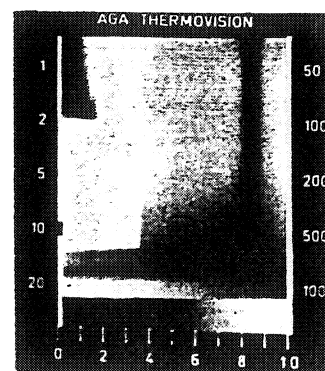
C1 mätområde/measuring range 10



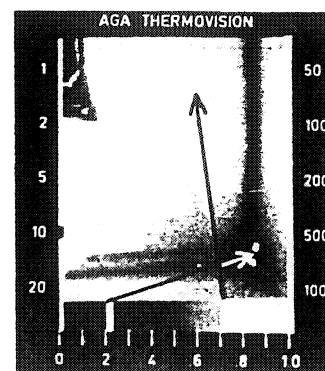
C2 mätområde/measuring range 20



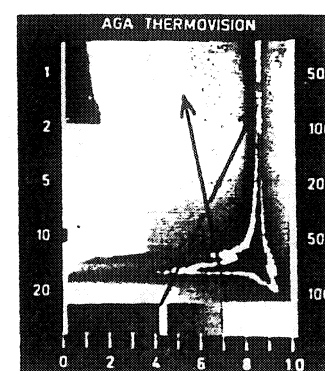
C3 $\Delta t = 4.0^\circ\text{C}$



D1



D2 $\Delta t = 8.9^\circ\text{C}$



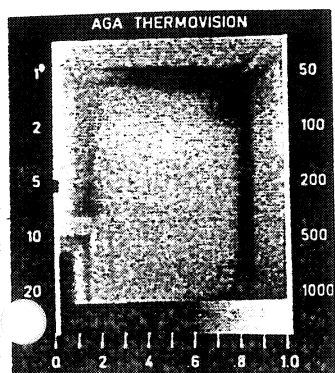
D3 $\Delta t = 4.8^\circ\text{C}$

Regelvägg nr 1 / Framed cladding panel No. 1
 Konstruktion med inbyggda fel / Design with deliberate faults

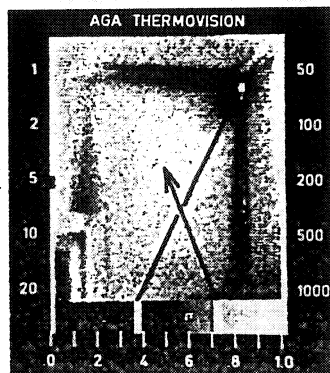
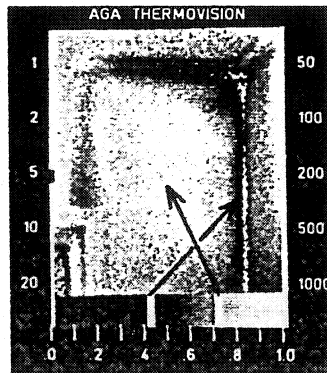
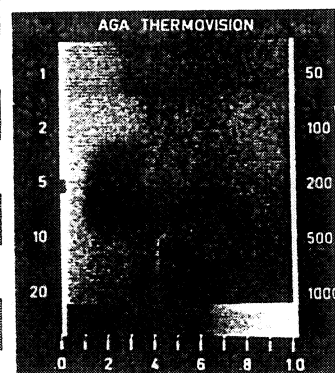
120 mm mineralull / Mineral wool

Temperaturskillnad (inne – ute) /
 Difference in temperature (indoors – outdoors): $t_i - t_u = 11^\circ\text{C}$

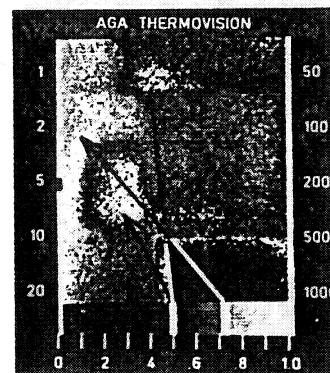
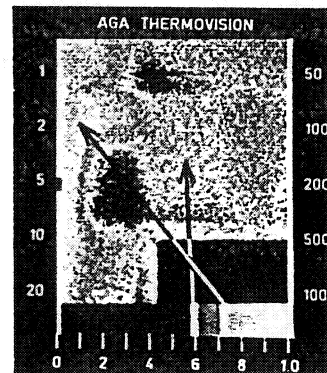
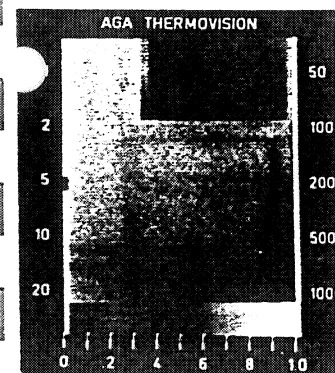
Tryckskillnad (inne – ute) /
 Difference in pressure (indoors – outdoors): $p_i - p_u = 0 \text{ N/m}^2$



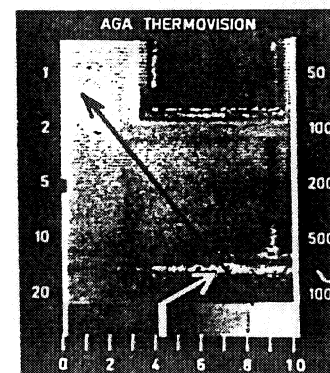
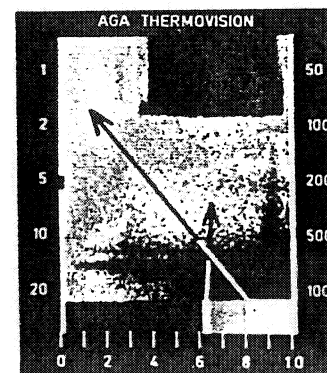
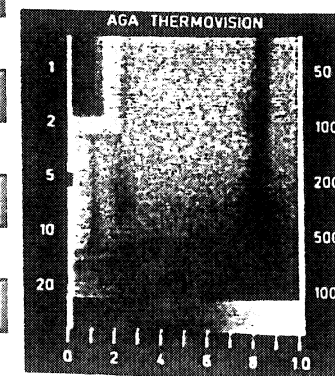
A1

A2 $\Delta t = 2.6^\circ\text{C}$ A3 $\Delta t = 2.2^\circ\text{C}$ 

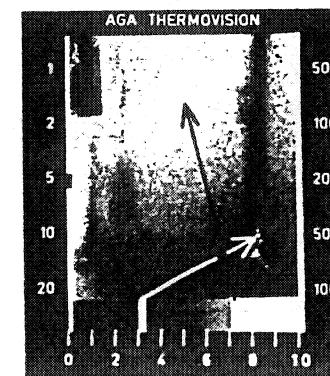
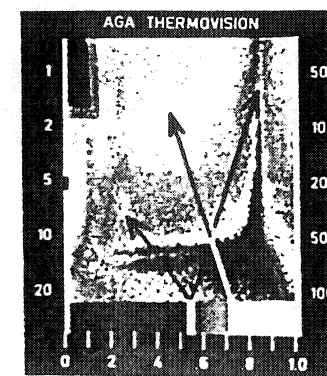
B1

B2 $\Delta t = 1.6^\circ\text{C}$ B3 $\Delta t = 0.9^\circ\text{C}$ 

C1

C2 $\Delta t = 3.1^\circ\text{C}$ C3 $\Delta t = 1.4^\circ\text{C}$ 

D1

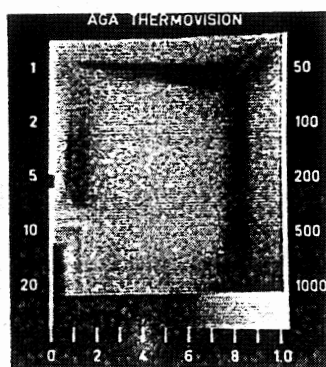
D2 $\Delta t = 3.2^\circ\text{C}$ D3 $\Delta t = 1.3^\circ\text{C}$

Regelvägg nr 1 / Framed cladding panel No. 1
Konstruktion med inbyggda fel / Design with deliberate faults

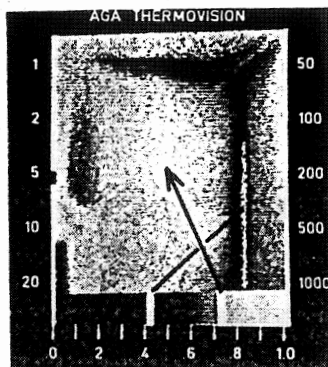
120 mm mineralull / Mineral wool

Temperaturskillnad (inne – ute) /
 Difference in temperature (indoors – outdoors): $t_i - t_u = 11^\circ\text{C}$

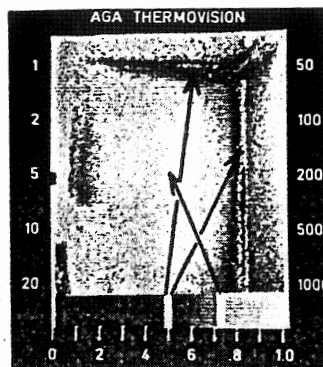
Tryckskillnad (inne – ute) /
 Difference in preasure (indoors – outdoors): $p_i - p_u = +50 \text{ N/m}^2$



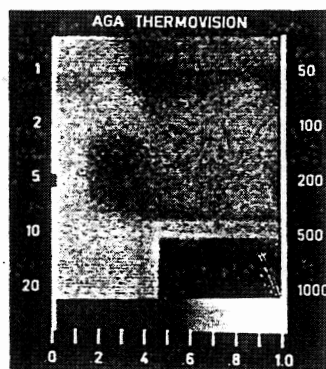
A1



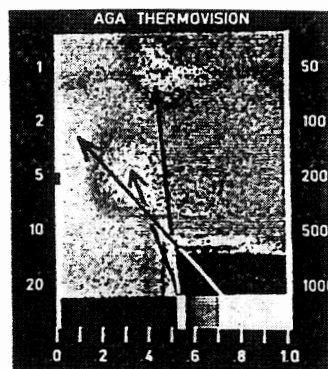
A2 $\Delta t = 2.3^\circ\text{C}$



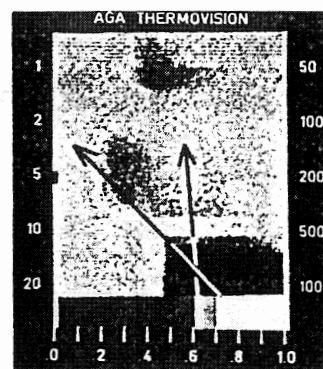
A3 $\Delta t = 1.7^\circ\text{C}$



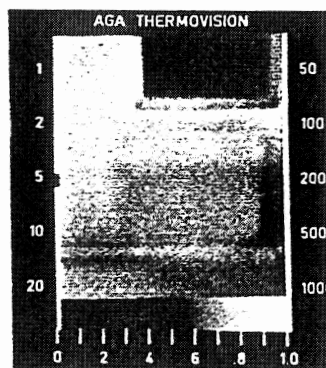
B1



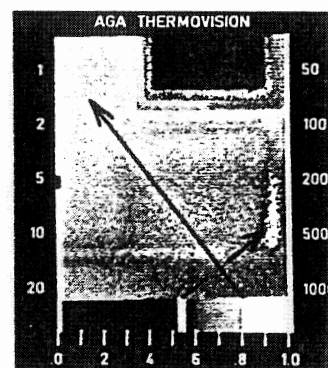
B2 $\Delta t = 1.3^\circ\text{C}$



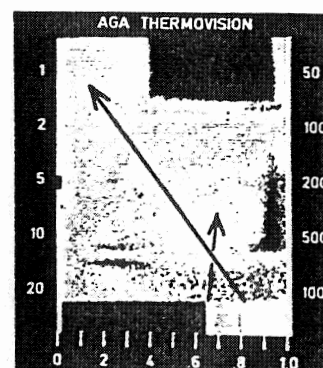
B3 $\Delta t = 0.6^\circ\text{C}$



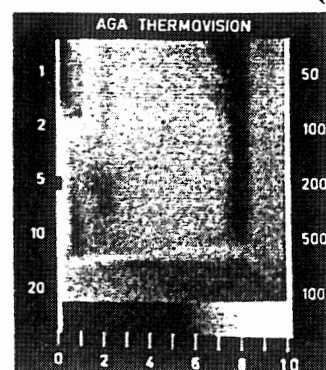
C1



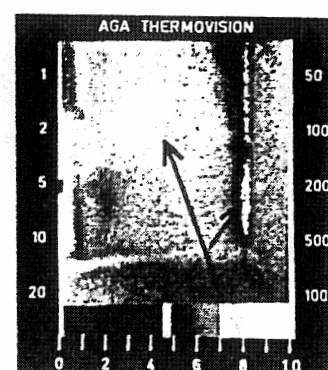
C2 $\Delta t = 2.2^\circ\text{C}$



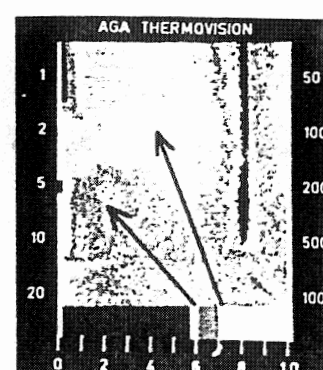
C3 $\Delta t = 1.2^\circ\text{C}$



D1



D2 $\Delta t = 1.9^\circ\text{C}$



D3 $\Delta t = 1.0^\circ\text{C}$

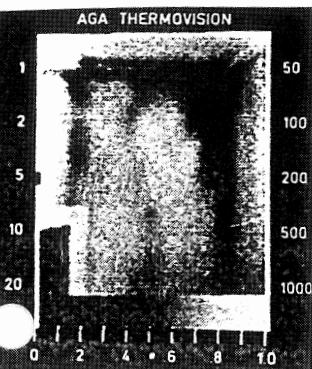
20 mm mineralull / Mineral wool

Temperaturskillnad (inne – ute) /

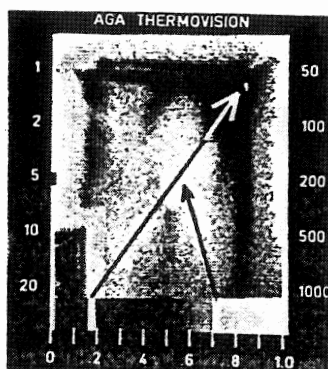
Difference in temperature (indoors – outdoors): $t_i - t_u = 11^\circ\text{C}$

Tryckskillnad (inne – ute) /

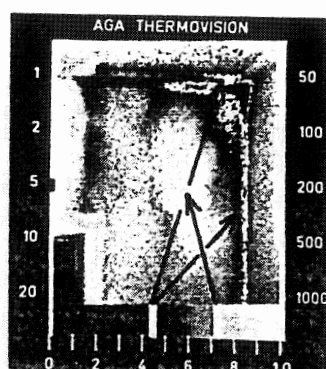
Difference in pressure (indoors – outdoors): $p_i - p_u = -50 \text{ N/m}^2$



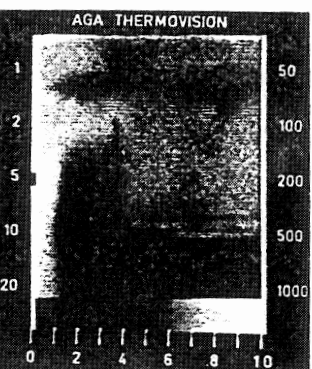
A1



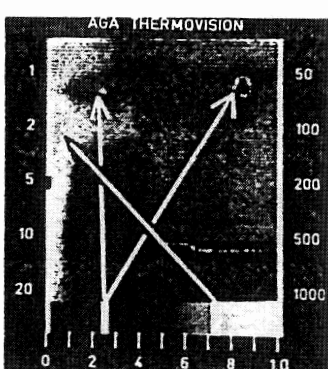
A2 $\Delta t = 4.4^\circ\text{C}$



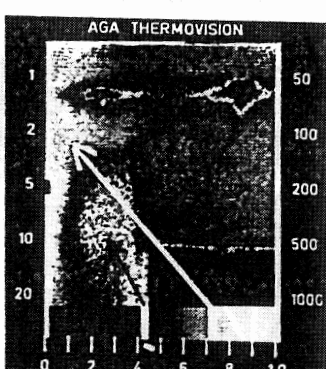
A3 $\Delta t = 2.1^\circ\text{C}$



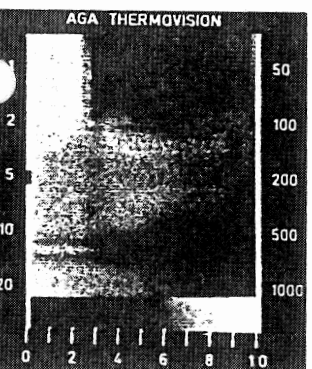
B1



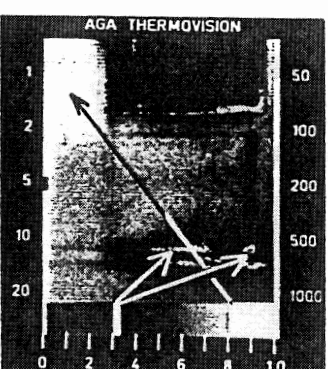
B2 $\Delta t = 3.7^\circ\text{C}$



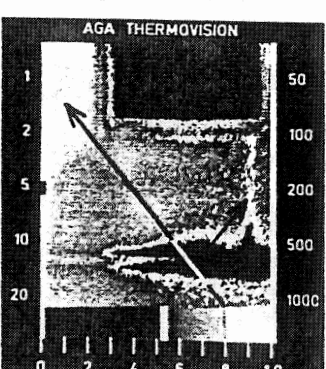
B3 $\Delta t = 2.2^\circ\text{C}$



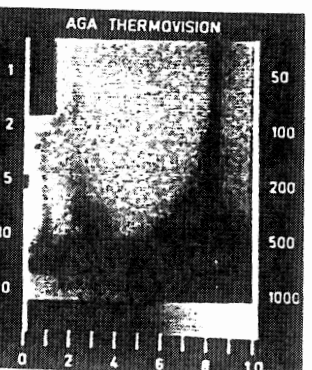
C1



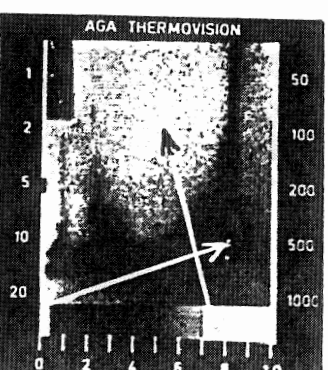
C2 $\Delta t = 4.0^\circ\text{C}$



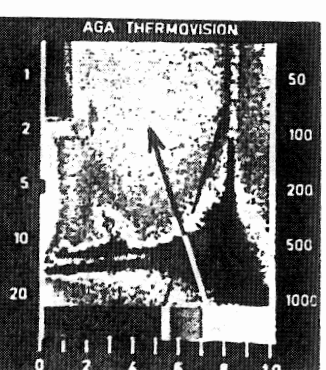
C3 $\Delta t = 2.2^\circ\text{C}$



D1



D2 $\Delta t = 5.7^\circ\text{C}$



D3 $\Delta t = 1.4^\circ\text{C}$

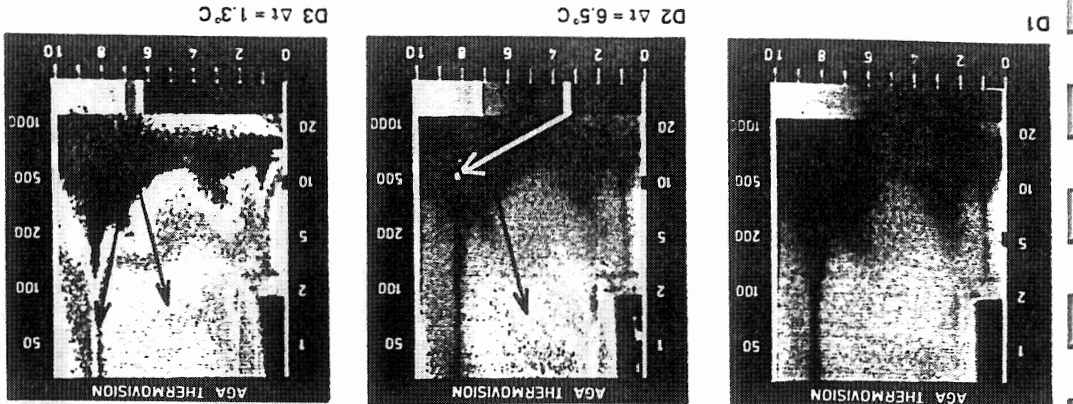
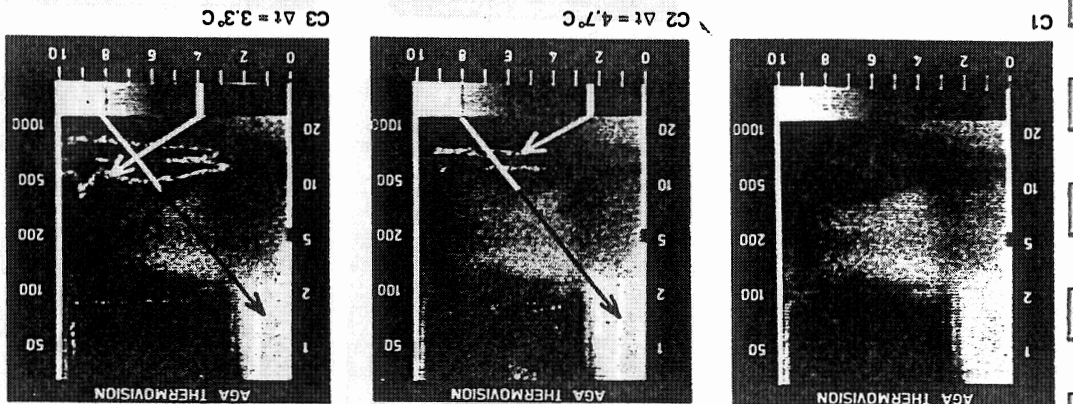
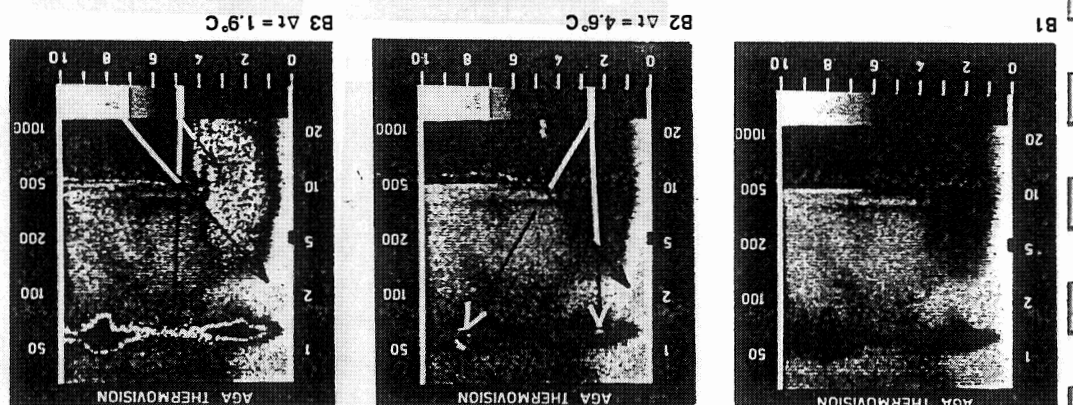
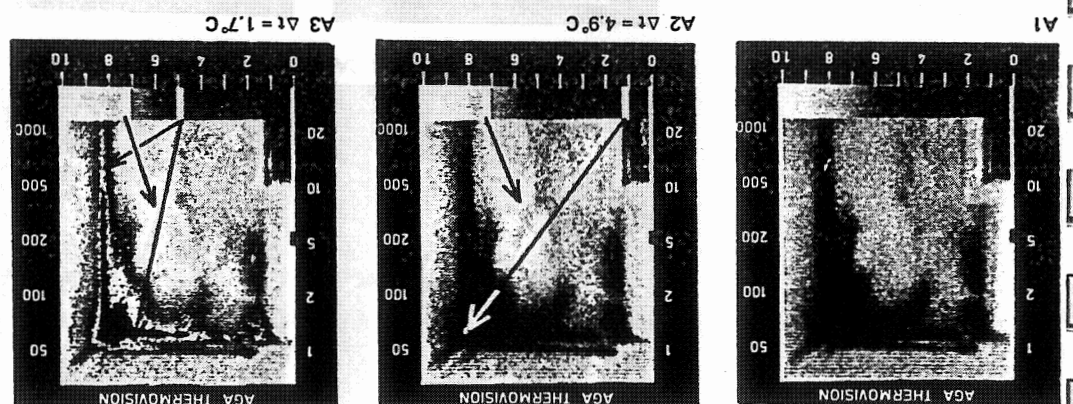
120 mm mineralull / Mineral wool

Temperaturskillnad (inne – ute) /

Difference in temperature (indoors – outdoors): $t_i - t_u = 11^\circ\text{C}$

Tryckskillnad (inne – ute) /

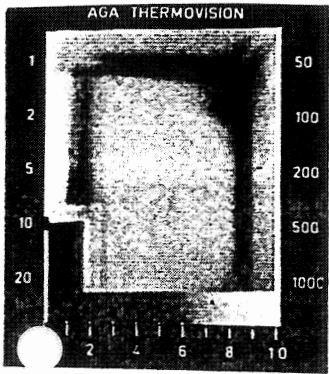
Difference in pressure (indoors – outdoors): $p_i - p_u = -100\text{ N/m}^2$



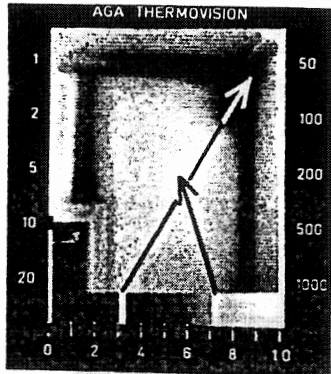
120 mm mineralull / Mineral wool

Temperaturskillnad (inne – ute) /
 Difference in temperature (indoors – outdoors): $t_i - t_u = 26^\circ\text{C}$

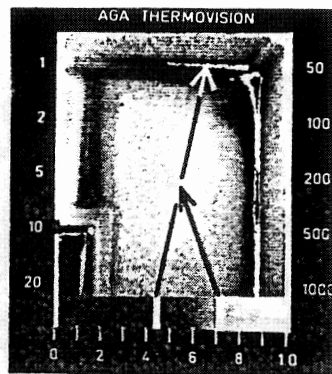
Tryckskillnad (inne – ute) /
 Difference in pressure (indoors – outdoors): $p_i - p_u = 0\text{ N/m}^2$



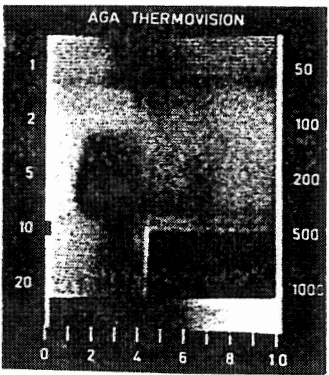
A1



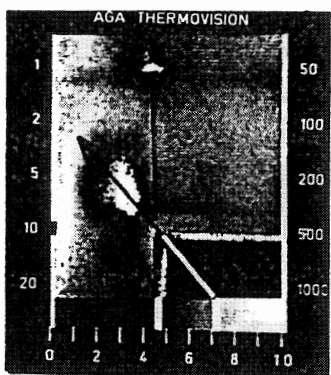
A2 $\Delta t = 6.8^\circ\text{C}$



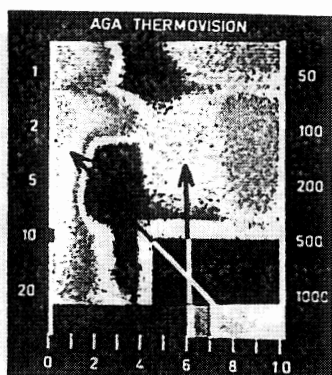
A3 $\Delta t = 4.4^\circ\text{C}$



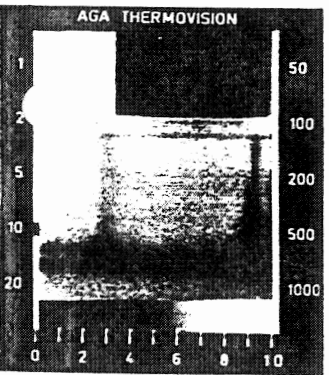
B1



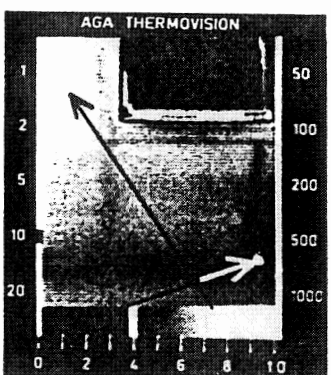
B2 $\Delta t = 4.0^\circ\text{C}$



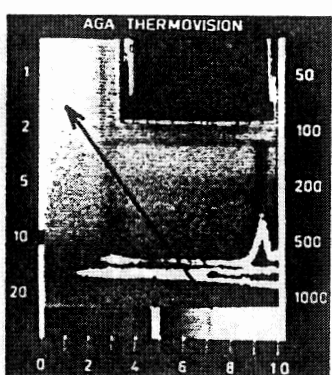
B3 $\Delta t = 1.6^\circ\text{C}$



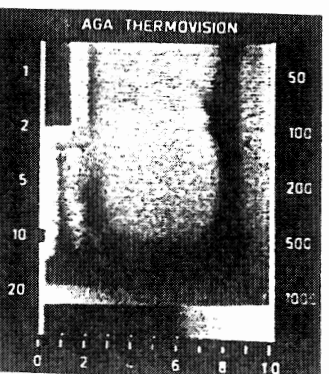
C1



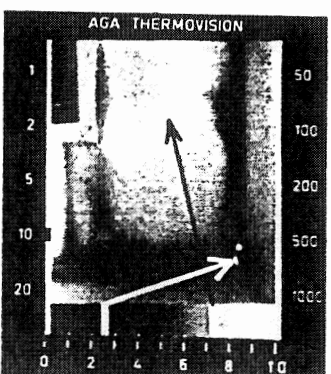
C2 $\Delta t = 5.6^\circ\text{C}$



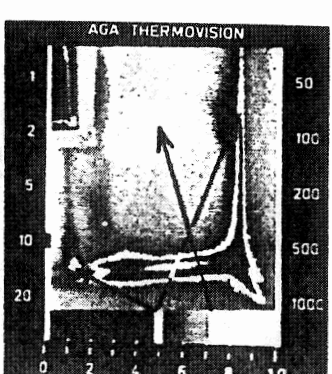
C3 $\Delta t = 3.6^\circ\text{C}$



D1



D2 $\Delta t = 8.0^\circ\text{C}$



D3 $\Delta t = 3.6^\circ\text{C}$

Regelvägg nr 1 / Framed cladding panel No. 1
 Konstruktion med inbyggda fel / Design with deliberate faults

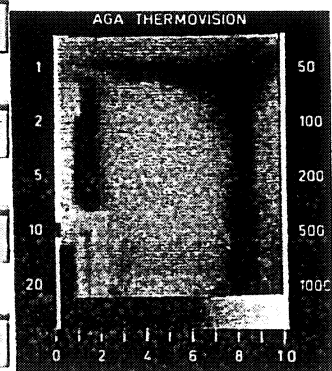
120 mm mineralull / Mineral wool

Temperaturskillnad (inne – ute) /

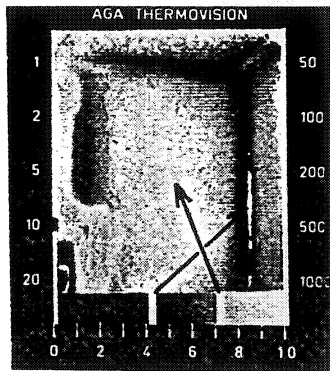
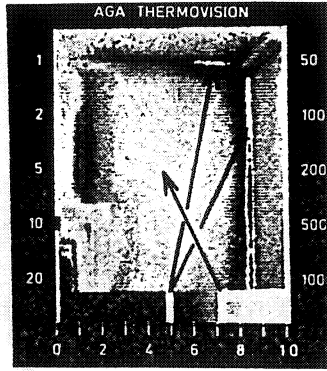
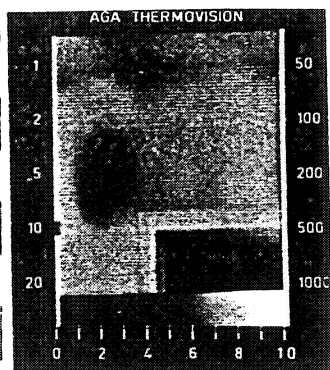
Difference in temperature (indoors – outdoors): $t_i - t_u = 26^\circ\text{C}$

Tryckskillnad (inne – ute) /

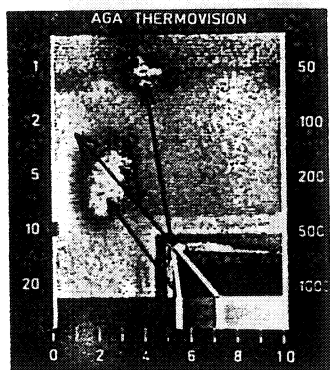
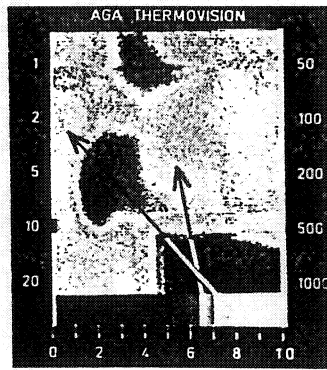
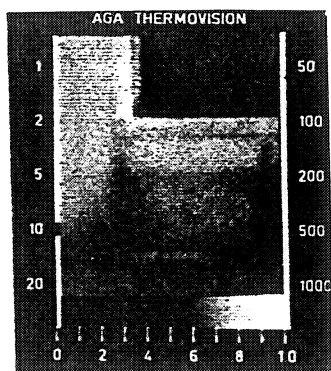
Difference in pressure (indoors – outdoors): $p_i - p_u = +50\text{ N/m}^2$



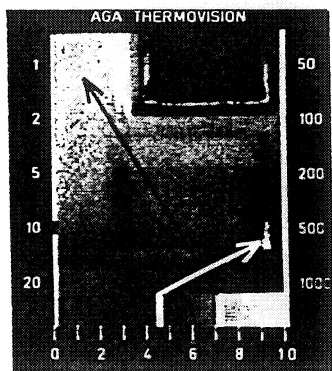
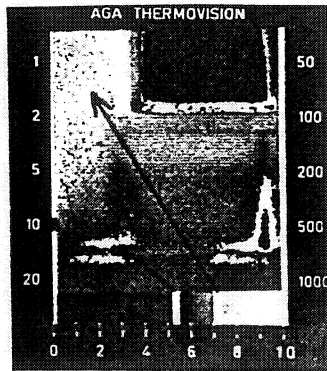
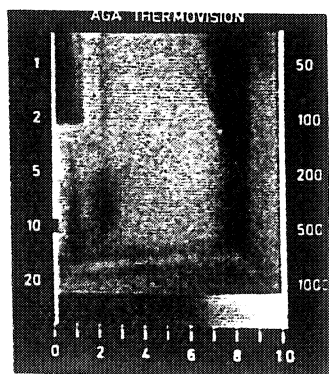
A1

A2 $\Delta t = 4.8^\circ\text{C}$ A3 $\Delta t = 3.5^\circ\text{C}$ 

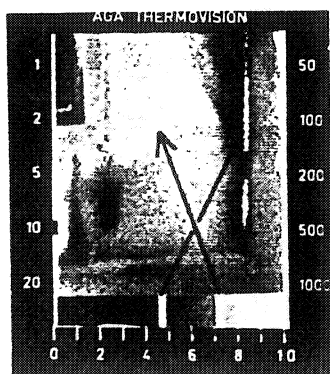
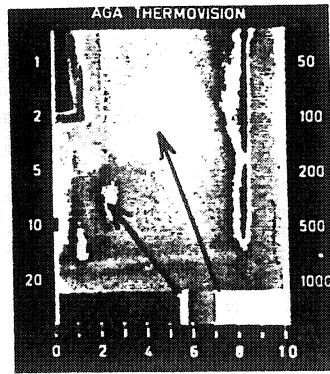
B1

B2 $\Delta t = 2.6^\circ\text{C}$ B3 $\Delta t = 0.8^\circ\text{C}$ 

C1

C2 $\Delta t = 4.3^\circ\text{C}$ C3 $\Delta t = 2.9^\circ\text{C}$ 

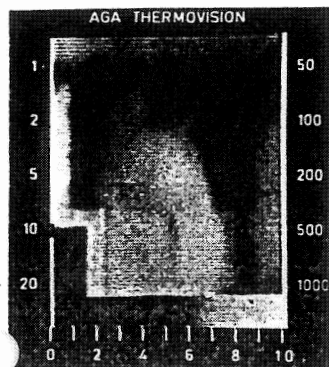
D1

D2 $\Delta t = 3.9^\circ\text{C}$ D3 $\Delta t = 2.4^\circ\text{C}$

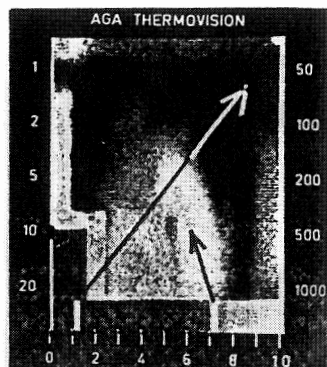
120 mm mineralull / Mineral wool

Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 26^\circ\text{C}$

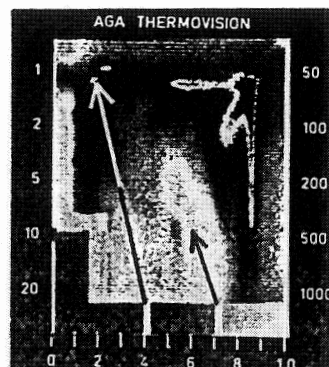
Tryckskillnad (inne – ute) /
Difference in pressure (indoors – outdoors): $p_i - p_u = -50\text{ N/m}^2$



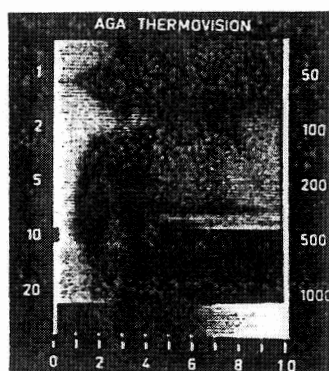
A1



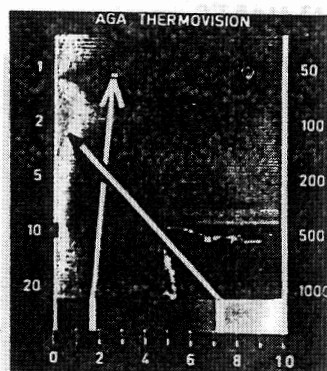
A2 $\Delta t = 10.8^\circ\text{C}$



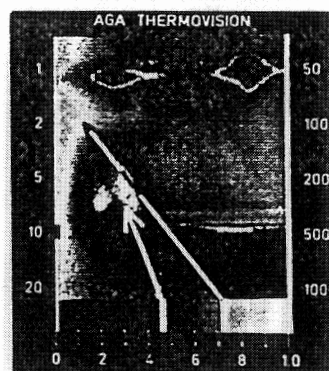
A3 $\Delta t = 5.0^\circ\text{C}$



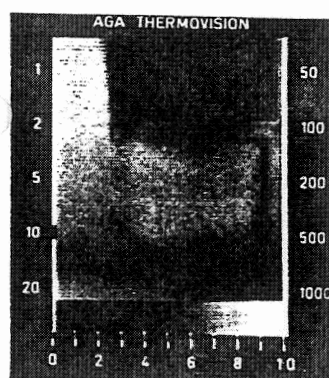
B1



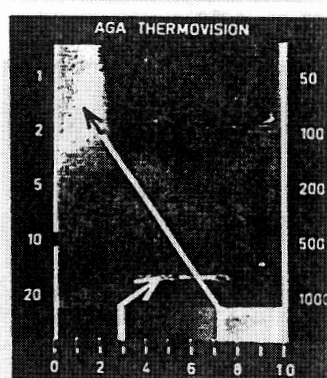
B2 $\Delta t = 9.6^\circ\text{C}$



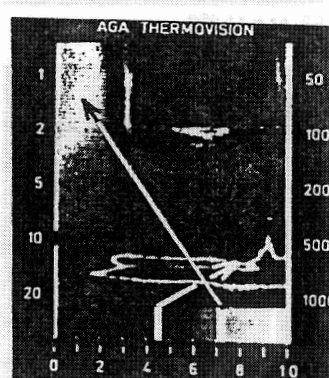
B3 $\Delta t = 4.1^\circ\text{C}$



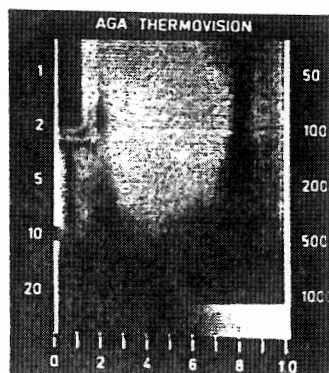
C1



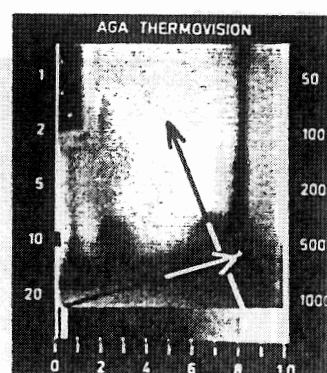
C2 $\Delta t = 7.3^\circ\text{C}$



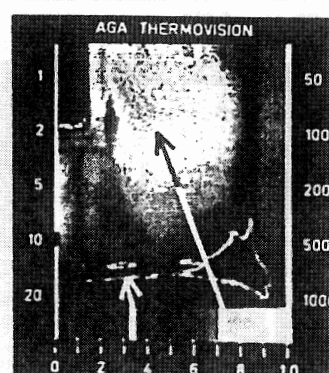
C3 $\Delta t = 4.3^\circ\text{C}$



D1



D2 $\Delta t = 14.9^\circ\text{C}$

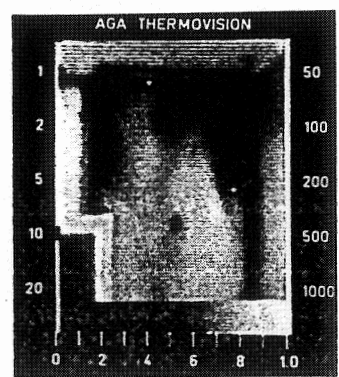


D3 $\Delta t = 6.4^\circ\text{C}$

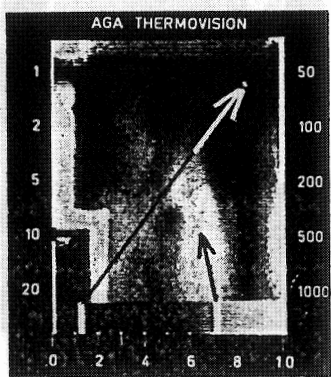
120 mm mineralull / Mineral wool

Temperaturskillnad (inne – ute) /
 Difference in temperature (indoors – outdoors): $t_i - t_u = 26^\circ\text{C}$

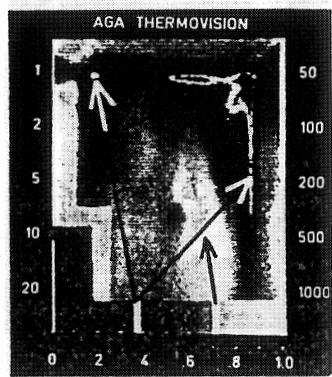
Tryckskillnad (inne – ute) /
 Difference in pressure (indoors – outdoors): $p_i - p_u = -100\text{ N/m}^2$



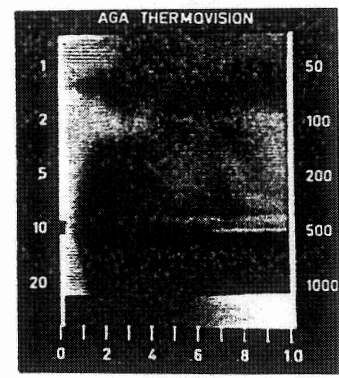
A1



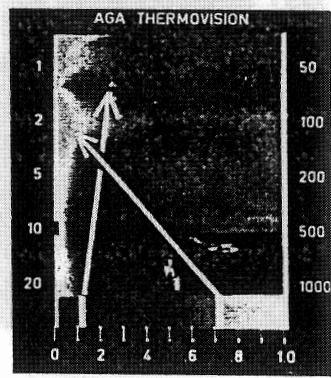
A2 $\Delta t = 11.6^\circ\text{C}$



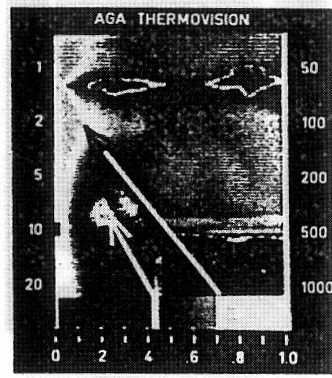
A3 $\Delta t = 5.7^\circ\text{C}$



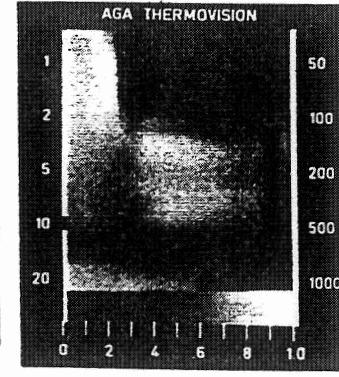
B1



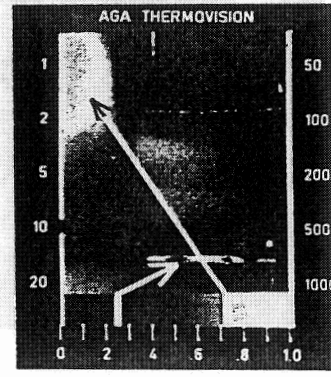
B2 $\Delta t = 11.9^\circ\text{C}$



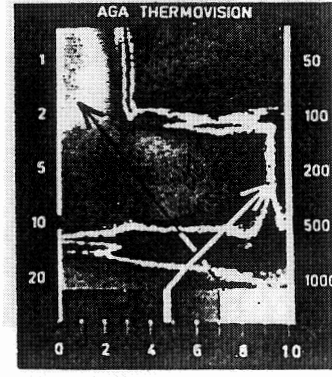
B3 $\Delta t = 4.7^\circ\text{C}$



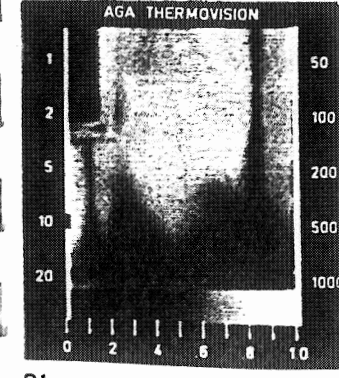
C1



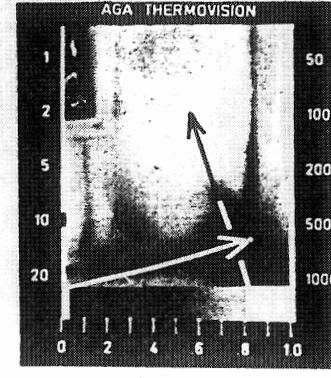
C2 $\Delta t = 8.0^\circ\text{C}$



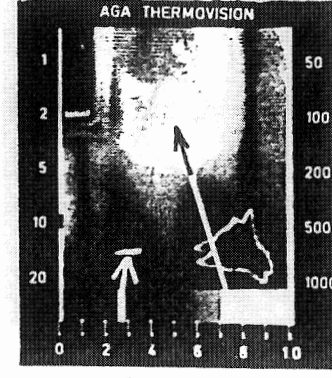
C3 $\Delta t = 3.9^\circ\text{C}$



D1



D2 $\Delta t = 15.4^\circ\text{C}$

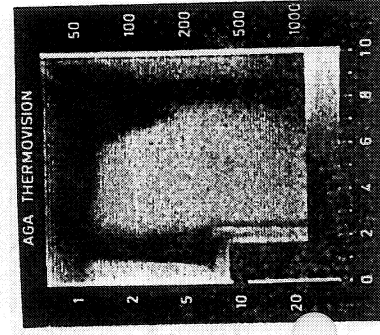


D3 $\Delta t = 7.6^\circ\text{C}$

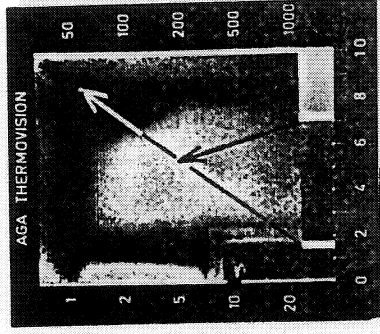
120 mm mineralull / Mineral wool

Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 41^\circ\text{C}$

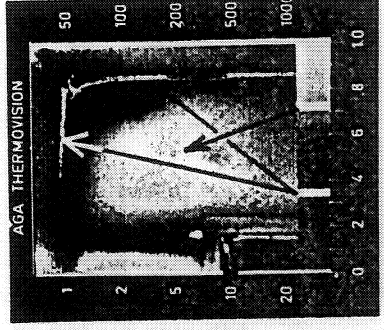
Tryckskillnad (inne – ute) /
Difference in pressure (indoors – outdoors): $p_i - p_u = 0 \text{ N/m}^2$



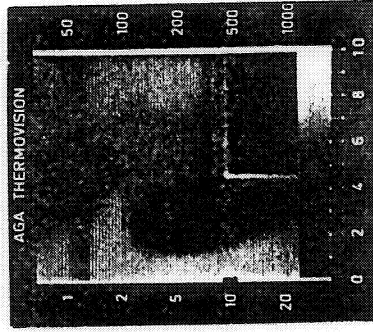
A1



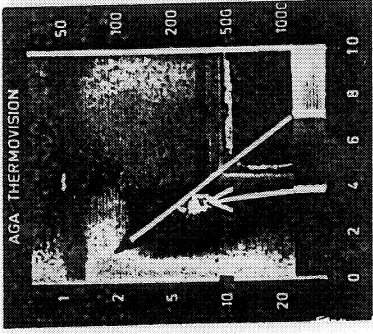
A2 $\Delta t = 10.0^\circ\text{C}$



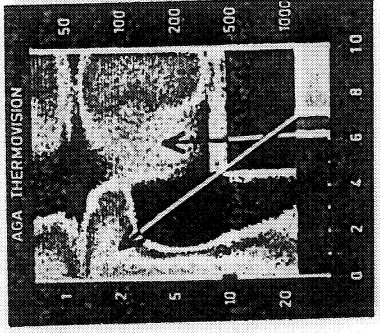
A3 $\Delta t = 6.3^\circ\text{C}$



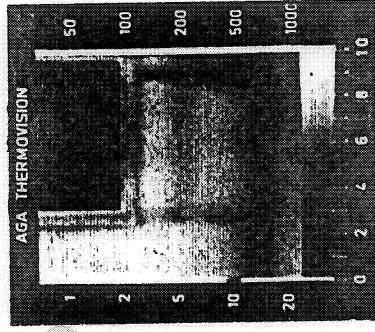
B1



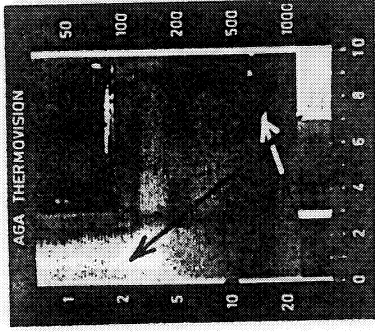
B2 $\Delta t = 5.5^\circ\text{C}$



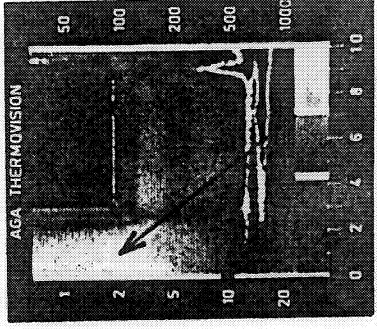
B3 $\Delta t = 1.5^\circ\text{C}$



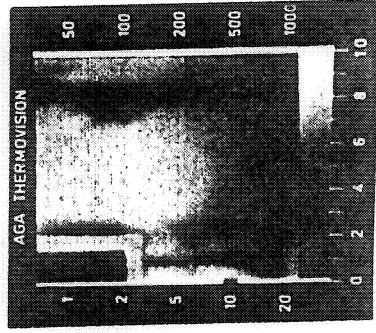
C1



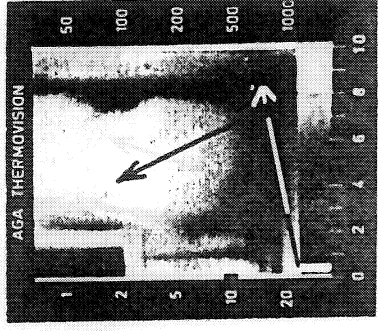
C2 $\Delta t = 7.5^\circ\text{C}$



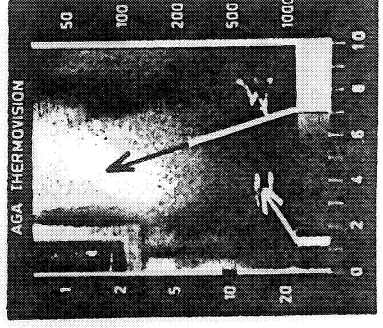
C3 $\Delta t = 4.8^\circ\text{C}$



D1



D2 $\Delta t = 15.2^\circ\text{C}$



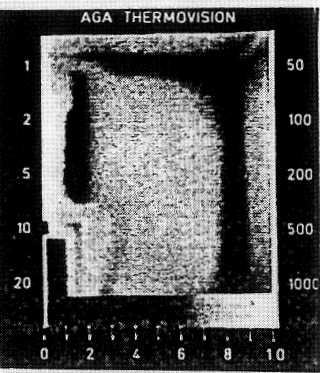
D3 $\Delta t = 10.7^\circ\text{C}$

Regelvägg nr 1 / Framed cladding panel No. 1
Konstruktion med inbyggda fel / Design with deliberate faults

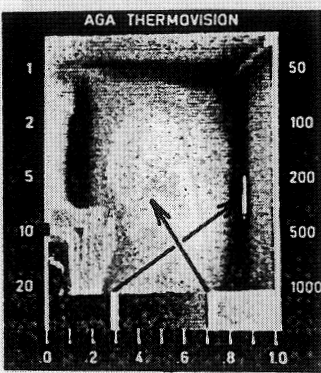
120 mm mineralull / Mineral wool

Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 41^\circ\text{C}$

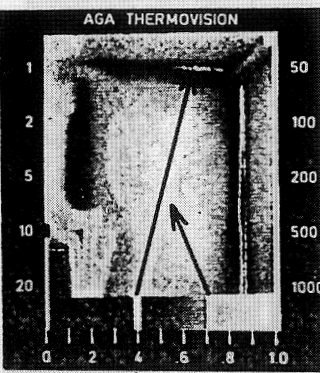
Tryckskillnad (inne – ute) /
Difference in pressure (indoors – outdoors): $p_i - p_u = +50\text{ N/m}^2$



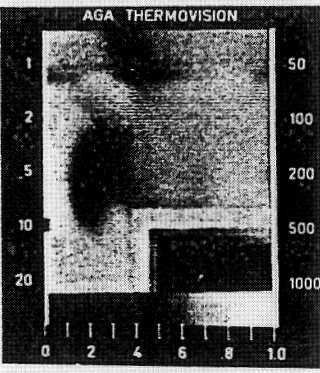
A1



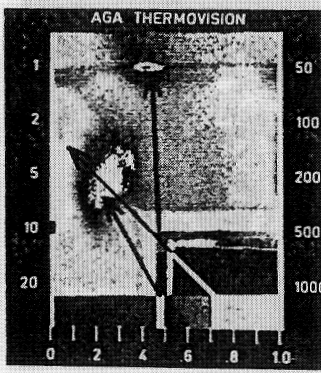
A2 $\Delta t = 7.2^\circ\text{C}$



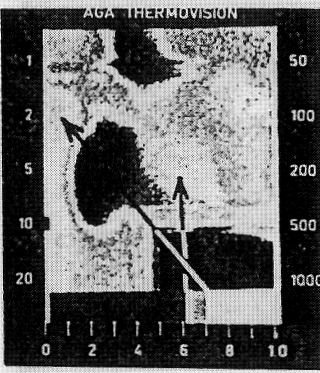
A3 $\Delta t = 5.4^\circ\text{C}$



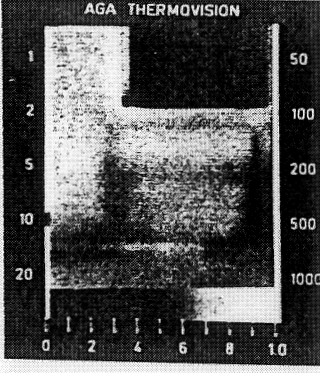
B1



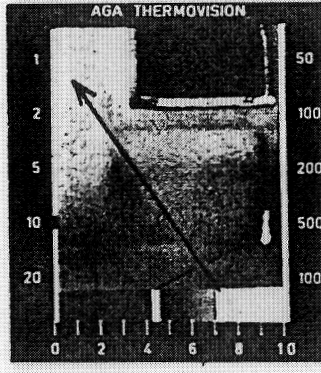
B2 $\Delta t = 3.8^\circ\text{C}$



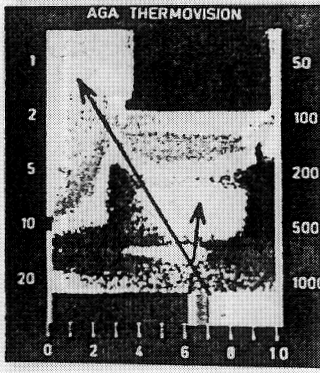
B3 $\Delta t = 1.4^\circ\text{C}$



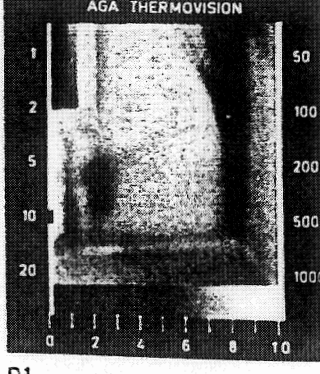
C1



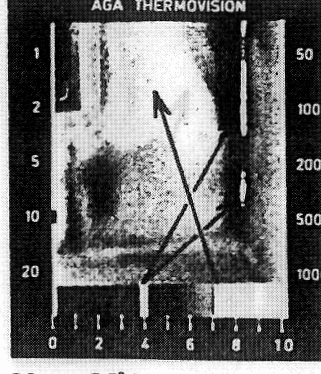
C2 $\Delta t = 4.8^\circ\text{C}$



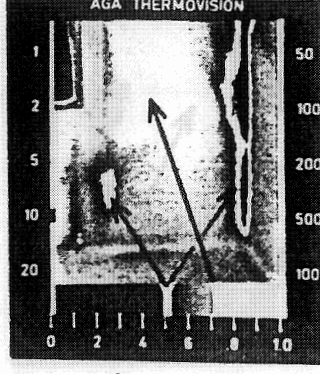
C3 $\Delta t = 1.3^\circ\text{C}$



D1



D2 $\Delta t = 5.5^\circ\text{C}$

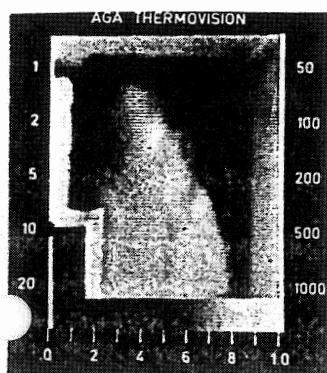


D3 $\Delta t = 3.4^\circ\text{C}$

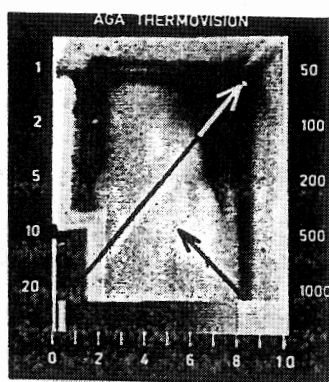
120 mm mineralull / Mineral wool

Temperaturskillnad (inne – ute) /
 Difference in temperature (indoors – outdoors): $t_i - t_u = 41^\circ\text{C}$

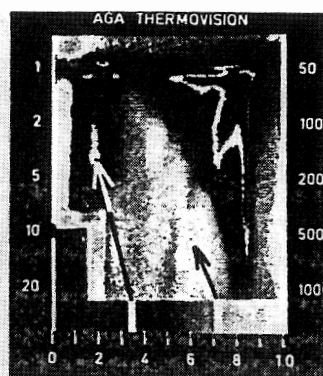
Tryckskillnad (inne – ute) /
 Difference in pressure (indoors – outdoors): $p_i - p_u = -50 \text{ N/m}^2$



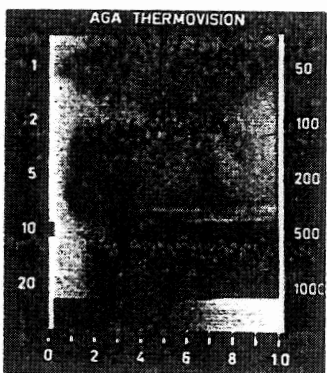
A1



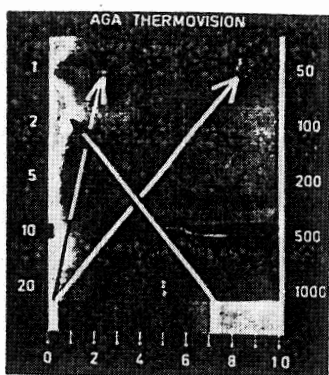
A2 $\Delta t = 15.3^\circ\text{C}$



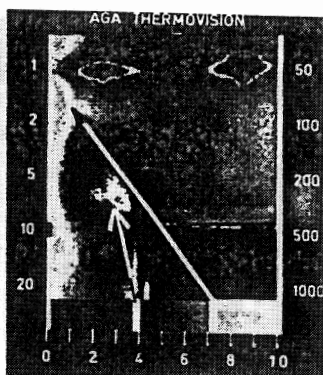
A3 $\Delta t = 6.5^\circ\text{C}$



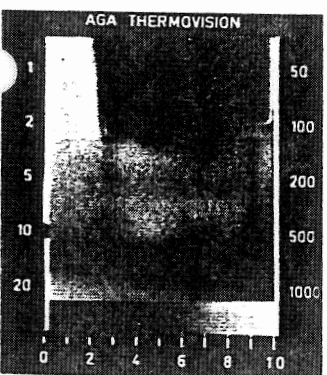
B1



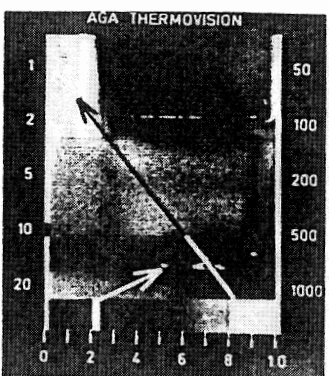
B2 $\Delta t = 13.5^\circ\text{C}$



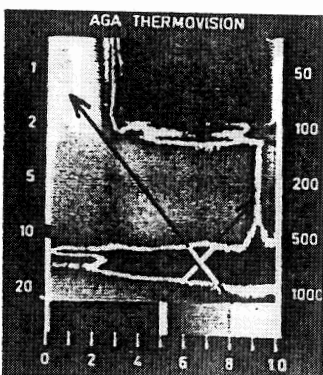
B3 $\Delta t = 5.8^\circ\text{C}$



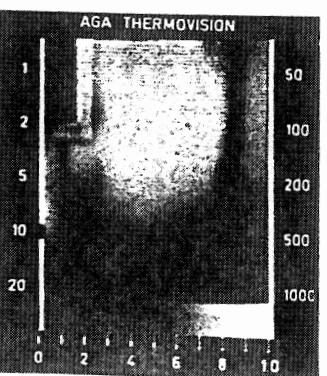
C1



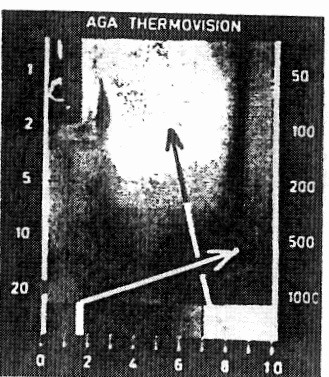
C2 $\Delta t = 11.0^\circ\text{C}$



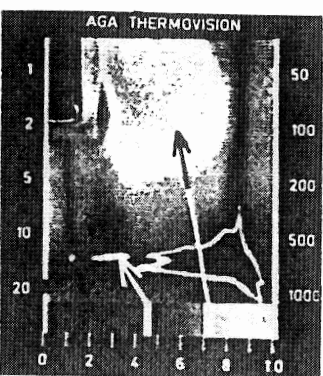
C3 $\Delta t = 5.2^\circ\text{C}$



D1



D2 $\Delta t = 24.7^\circ\text{C}$

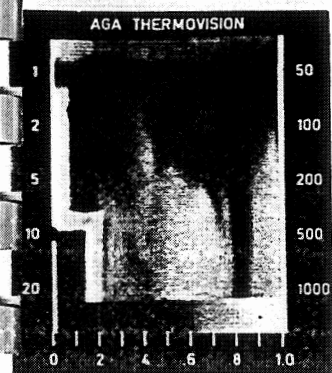


D3 $\Delta t = 9.4^\circ\text{C}$

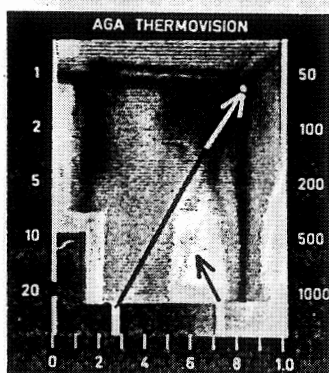
20 mm mineralull / Mineral wool

Temperaturskillnad (inne – ute) /
 Difference in temperature (indoors – outdoors): $t_i - t_u = 41^\circ\text{C}$

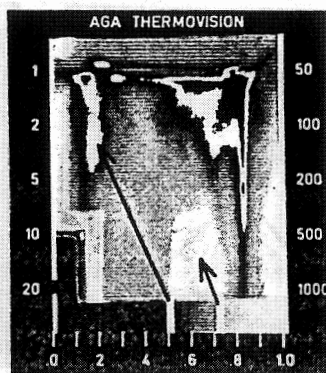
Tryckskillnad (inne – ute) /
 Difference in pressure (indoors – outdoors): $p_i - p_u = -100 \text{ N/m}^2$



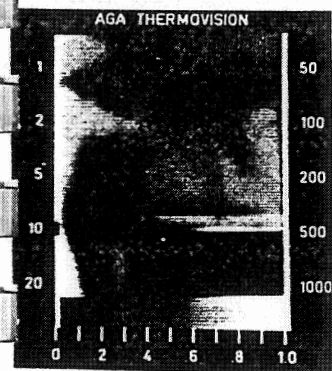
A1



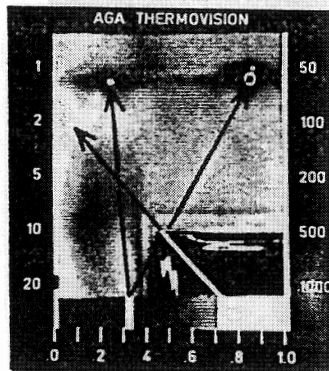
A2 $\Delta t = 18.2^\circ\text{C}$



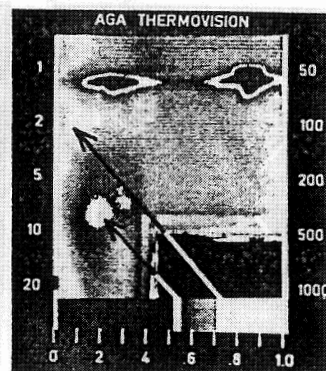
A3 $\Delta t = 7.4^\circ\text{C}$



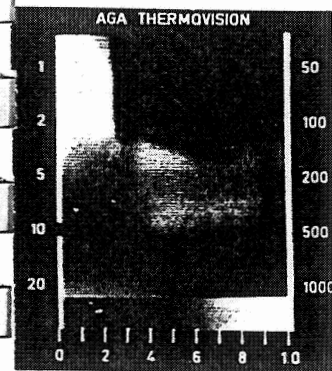
B1



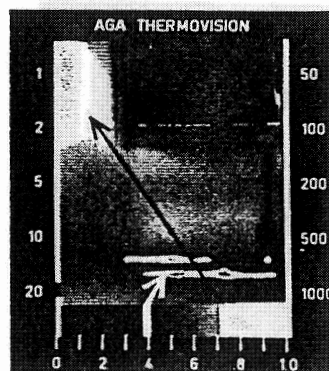
B2 $\Delta t = 16.1^\circ\text{C}$



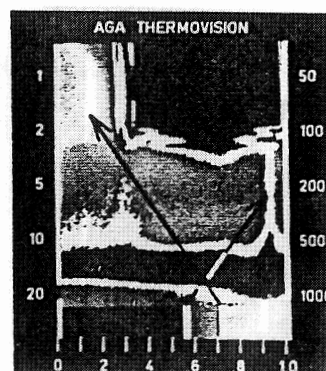
B3 $\Delta t = 6.6^\circ\text{C}$



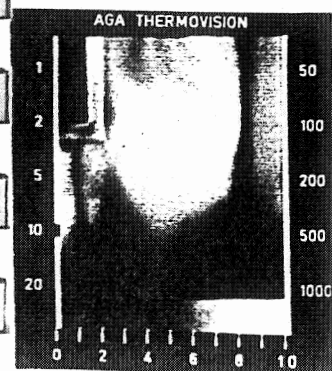
C1



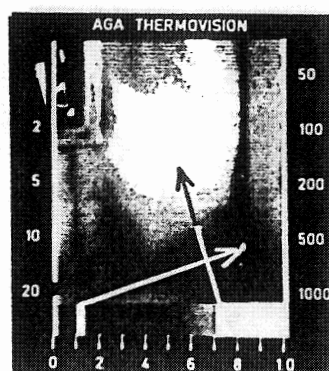
C2 $\Delta t = 14.6^\circ\text{C}$



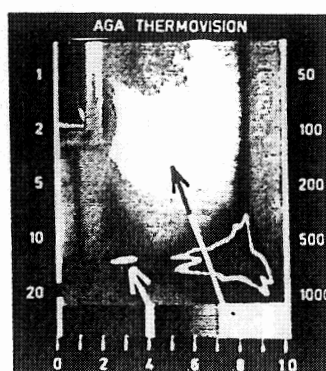
C3 $\Delta t = 5.2^\circ\text{C}$



D1



D2 $\Delta t = 27.2^\circ\text{C}$



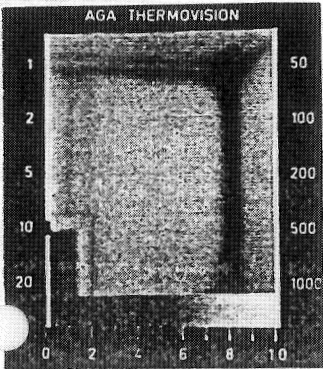
D3 $\Delta t = 11.6^\circ\text{C}$

100 mm mineralull och 30 mm cellplast /
100 mm mineral wool and 30 mm cellular plastic

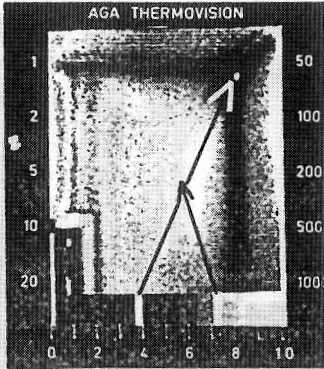
Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 26^\circ\text{C}$

Tryckskillnad (inne – ute) /
Difference in pressure (indoors – outdoors): $p_i - p_u = 0\text{ N/m}^2$

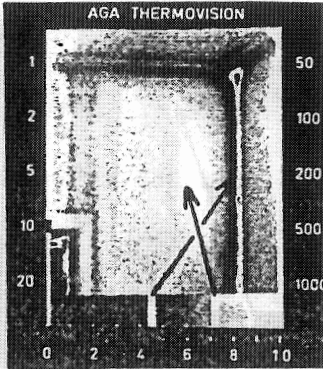
A4, B4, C4, D4	
vit/white	20.7 – 22.0°C
gul/yellow	19.1 – 20.6°C
röd/red	17.4 – 19.0°C
violett/purple	15.7 – 17.3°C
ljusgrön/light green	13.8 – 15.6°C
mörkgrön/dark green	11.9 – 13.7°C
ljusblå/light blue	9.9 – 11.8°C
mörkblå/dark blue	7.8 – 9.8°C



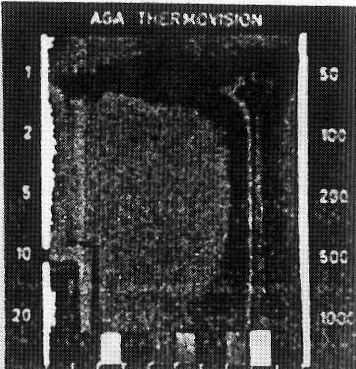
A1



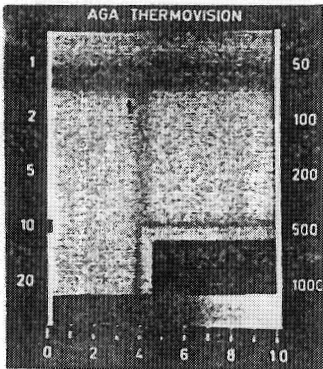
A2 $\Delta t = 5.4^\circ\text{C}$



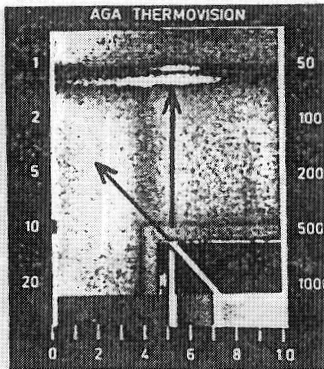
A3 $\Delta t = 4.2^\circ\text{C}$



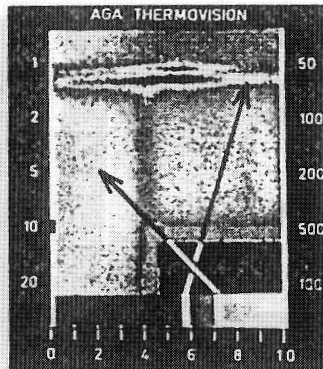
A4



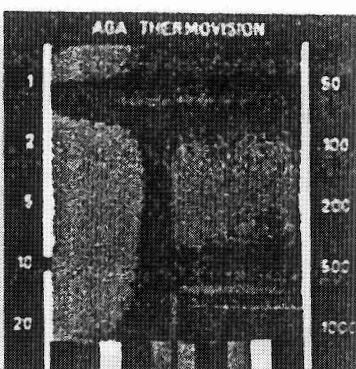
B1



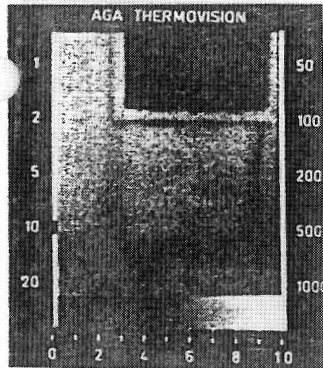
B2 $\Delta t = 3.1^\circ\text{C}$



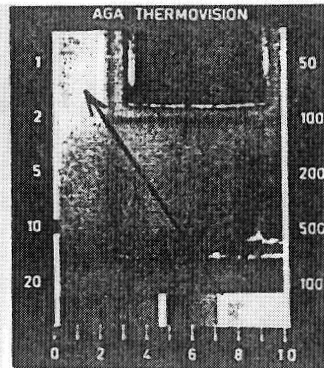
B3 $\Delta t = 2.0^\circ\text{C}$



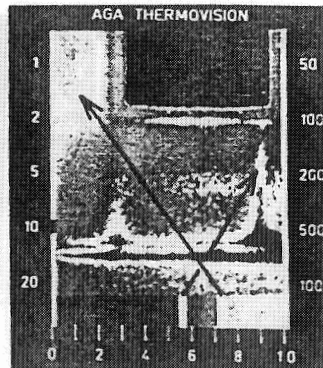
B4



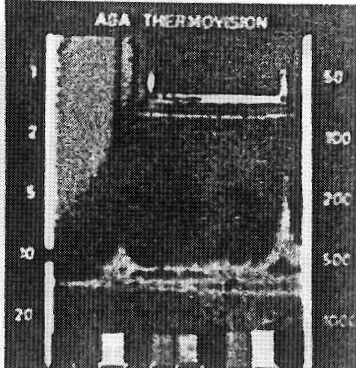
C1



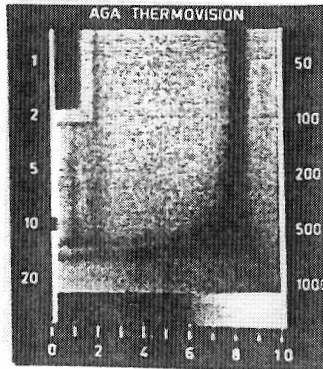
C2 $\Delta t = 3.9^\circ\text{C}$



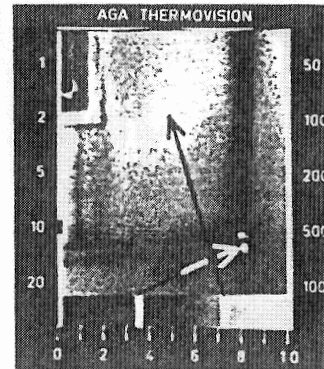
C3 $\Delta t = 2.4^\circ\text{C}$



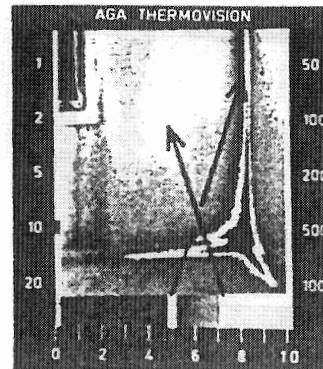
C4



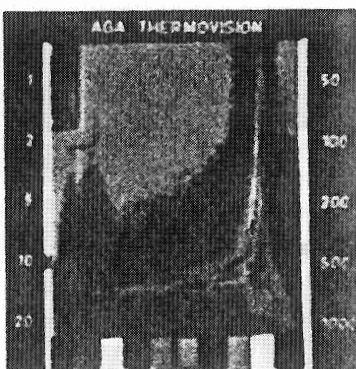
D1



D2 $\Delta t = 6.1^\circ\text{C}$



D3 $\Delta t = 3.4^\circ\text{C}$



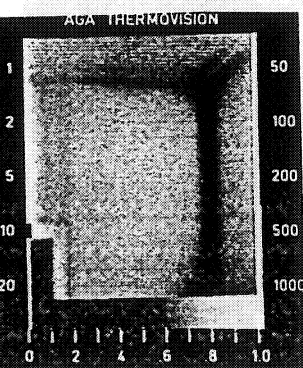
D4

0 mm mineralull och 30 mm cellplast /
 0 mm mineral wool and 30 mm cellular plastic

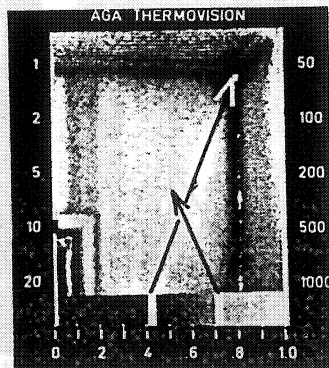
temperaturskillnad (inne – ute) /
 difference in temperature (indoors – outdoors): $t_i - t_u = 26^\circ\text{C}$

tryckskillnad (inne – ute) /
 difference in pressure (indoors – outdoors): $p_i - p_u = +50\text{ N/m}^2$

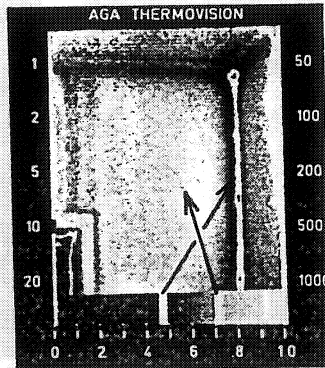
A4, B4, C4, D4	
vit/white	20.7 – 22.0°C
gul/yellow	19.1 – 20.6°C
röd/red	17.4 – 19.0°C
violett/purple	15.7 – 17.3°C
ljusgrön/light green	13.8 – 15.6°C
mörkgrön/dark green	11.9 – 13.7°C
ljusblå/light blue	9.9 – 11.8°C
mörkblå/dark blue	7.8 – 9.8°C



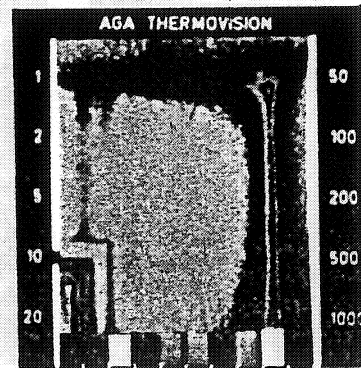
A1



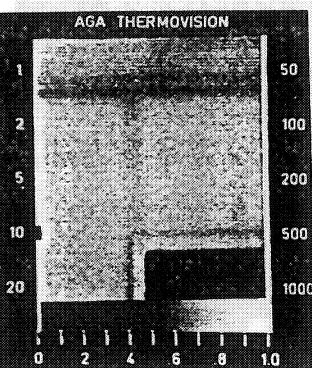
A2 $\Delta t = 4.7^\circ\text{C}$



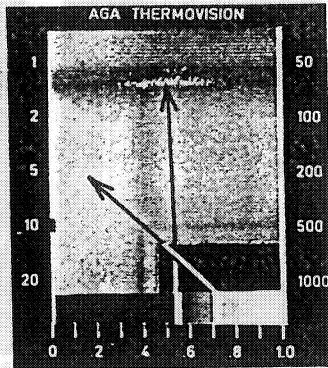
A3 $\Delta t = 3.9^\circ\text{C}$



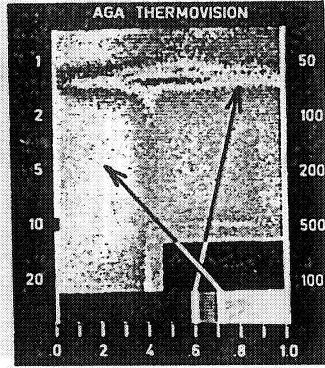
A4



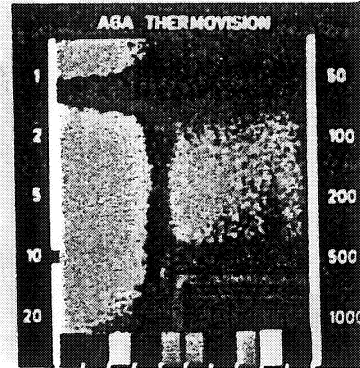
B1



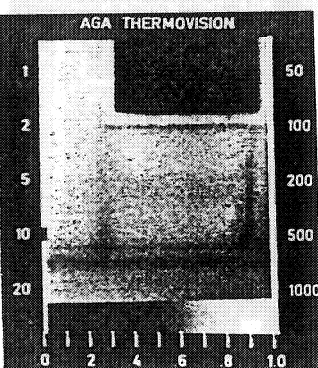
B2 $\Delta t = 2.5^\circ\text{C}$



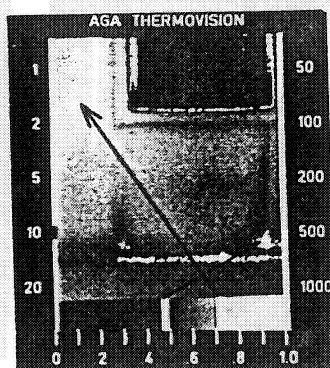
B3 $\Delta t = 1.6^\circ\text{C}$



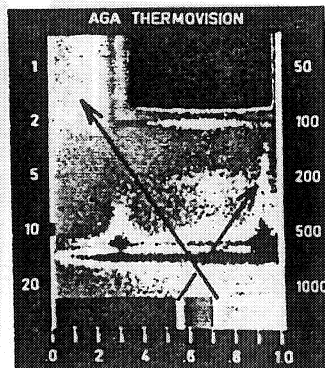
B4



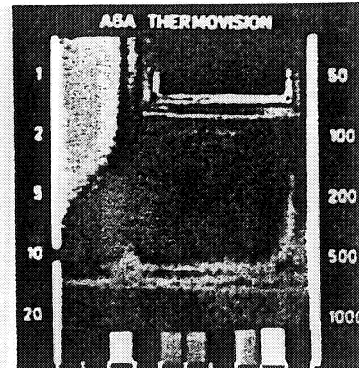
C1



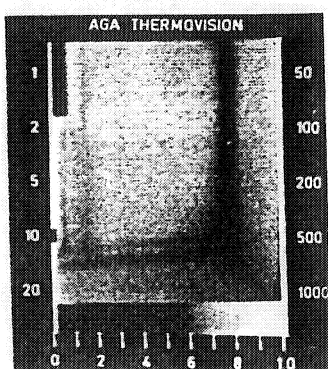
C2 $\Delta t = 3.7^\circ\text{C}$



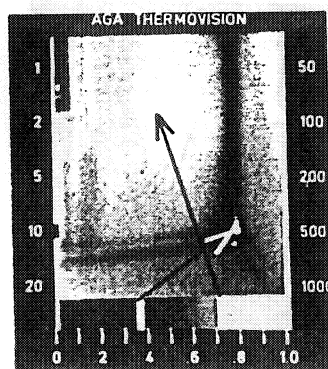
C3 $\Delta t = 2.4^\circ\text{C}$



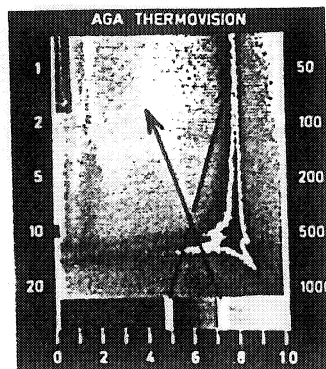
C4



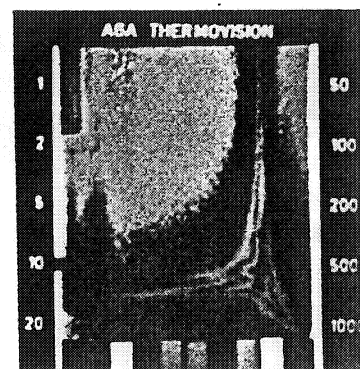
D1



D2 $\Delta t = 5.9^\circ\text{C}$



D3 $\Delta t = 3.6^\circ\text{C}$



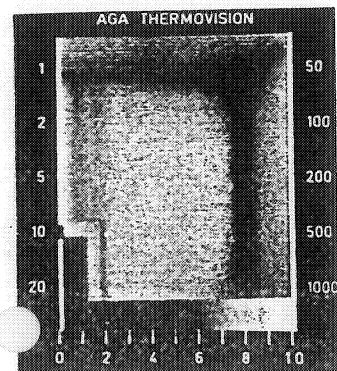
D4

100 mm mineralull och 30 mm cellplast /
100 mm mineral wool and 30 mm cellular plastic

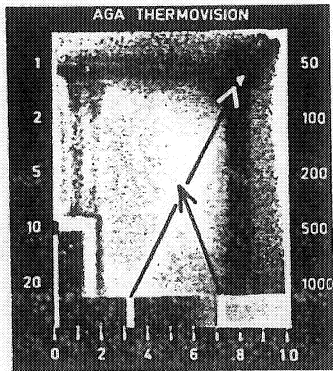
Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 26^\circ\text{C}$

Tryckskillnad (inne – ute) /
Difference in preasure (indoors – outdoors): $p_i - p_u = -50\text{ N/m}^2$

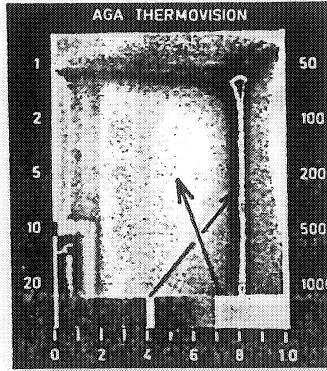
A4, B4, C4, D4	
vit/white	20.7 – 22.0°C
gul/yellow	19.1 – 20.6°C
röd/red	17.4 – 19.0°C
violett/purple	15.7 – 17.3°C
ljusgrön/light green	13.8 – 15.6°C
mörkgrön/dark green	11.9 – 13.7°C
ljusblå/light blue	9.9 – 11.8°C
mörkblå/dark blue	7.8 – 9.8°C



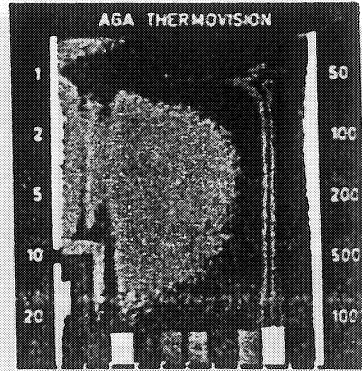
A1



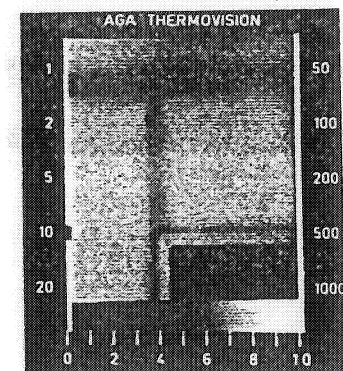
A2 $\Delta t = 6.5^\circ\text{C}$



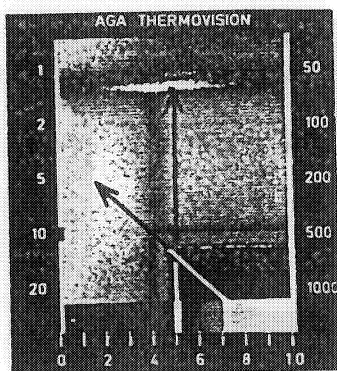
A3 $\Delta t = 4.9^\circ\text{C}$



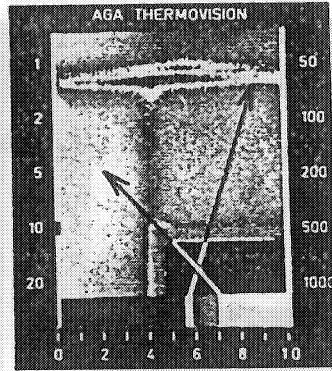
A4



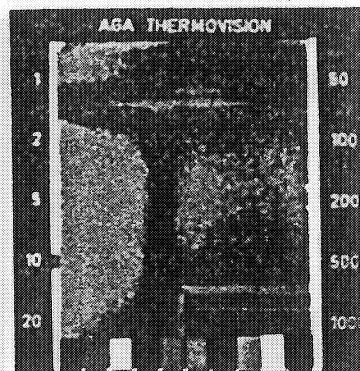
B1



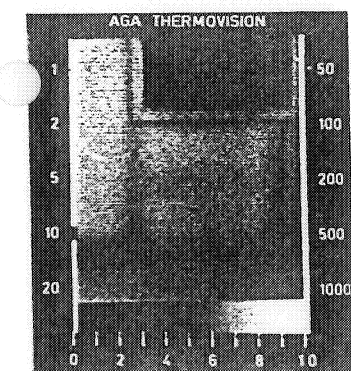
B2 $\Delta t = 3.3^\circ\text{C}$



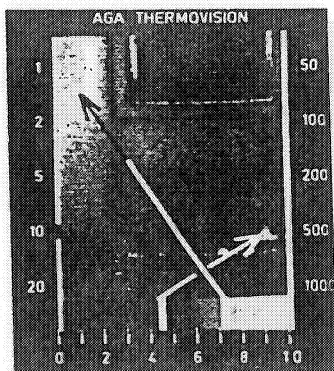
B3 $\Delta t = 2.1^\circ\text{C}$



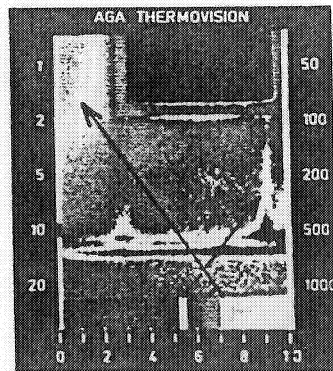
B4



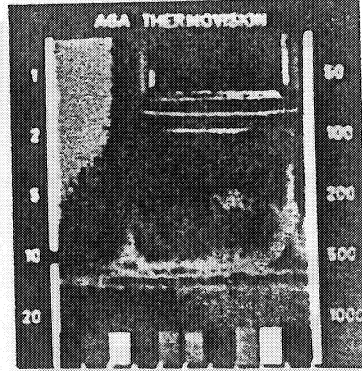
C1



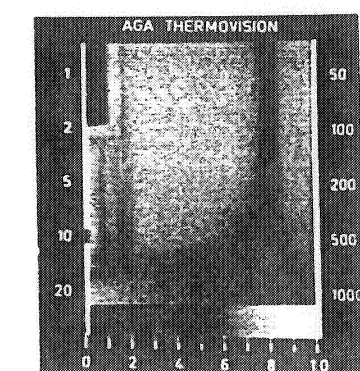
C2 $\Delta t = 4.3^\circ\text{C}$



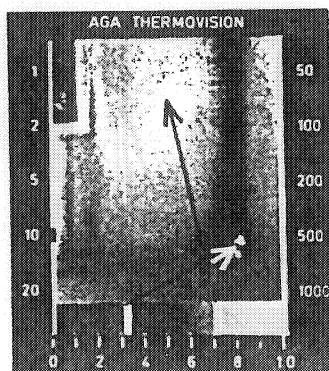
C3 $\Delta t = 2.7^\circ\text{C}$



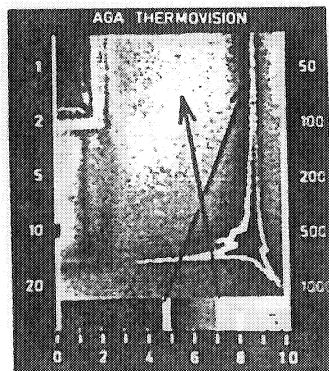
C4



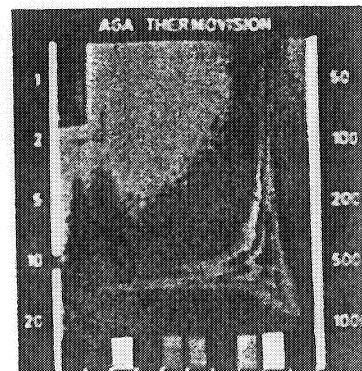
D1



D2 $\Delta t = 6.6^\circ\text{C}$



D3 $\Delta t = 3.7^\circ\text{C}$



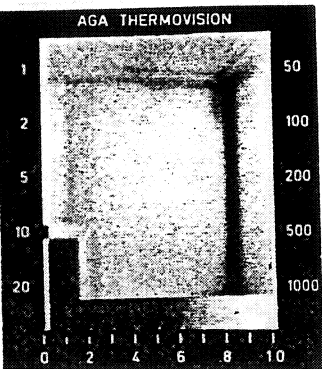
D4

Regelvägg nr 2 / Framed cladding panel No. 2
Konstruktion med inbyggda fel / Design with deliberate faults

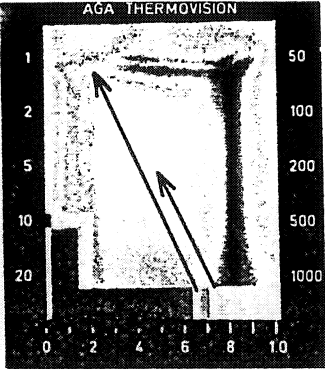
100 mm mineralull och 30 mm cellplast /
100 mm mineral wool and 30 mm cellular plastic

Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 26^\circ\text{C}$

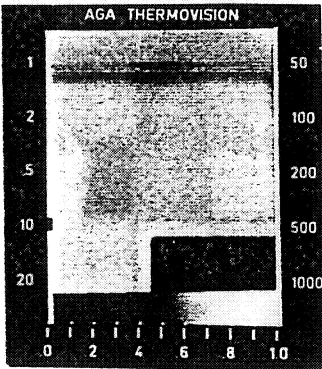
Tryckskillnad (inne – ute) /
Difference in pressure (indoors – outdoors): $p_i - p_u = 0\text{ N/m}^2$



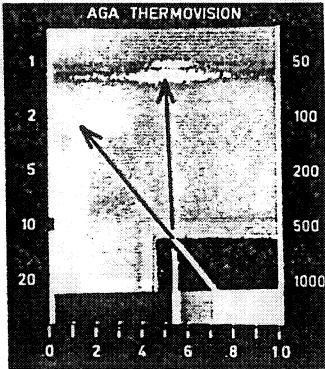
A1



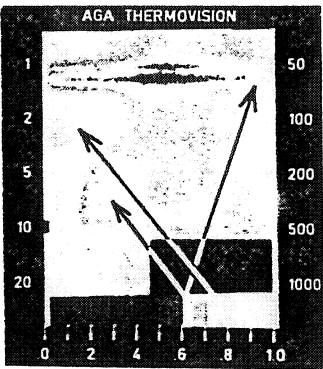
A2 $\Delta t = 1.1^\circ\text{C}$



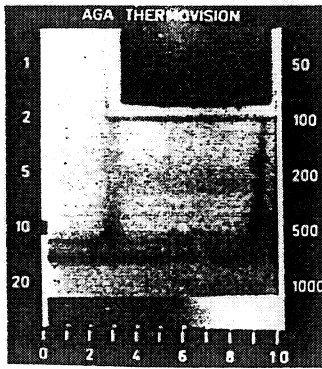
B1



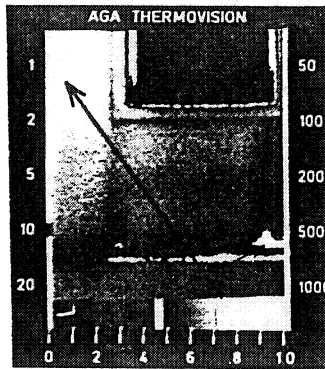
B2 $\Delta t = 2.7^\circ\text{C}$



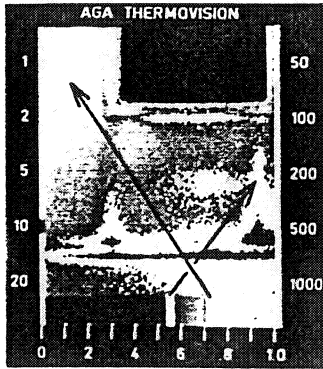
B3 $\Delta t = 1.6^\circ\text{C}$



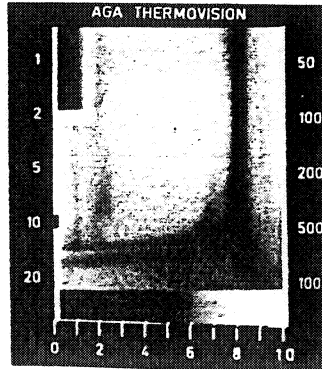
C1



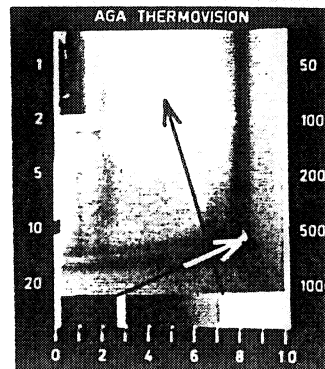
C2 $\Delta t = 4.2^\circ\text{C}$



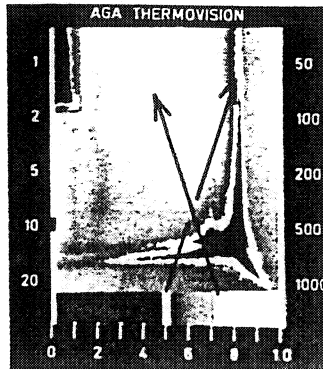
C3 $\Delta t = 2.7^\circ\text{C}$



D1



D2 $\Delta t = 6.6^\circ\text{C}$



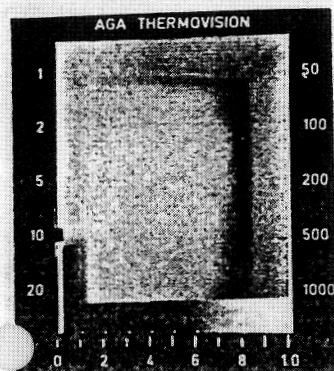
D3 $\Delta t = 3.5^\circ\text{C}$

Regelvägg nr 2 / Framed cladding panel No. 2 Konstruktion med inbyggda fel / Design with deliberate faults

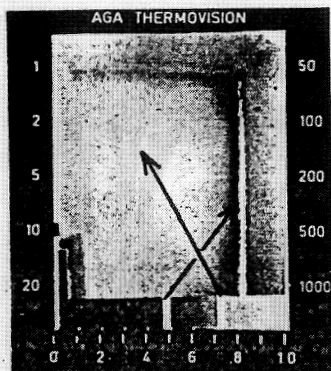
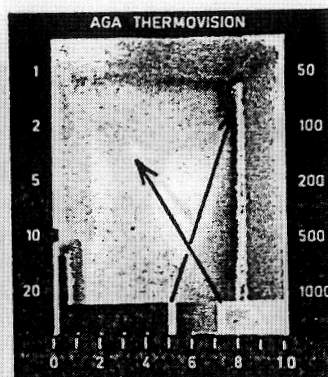
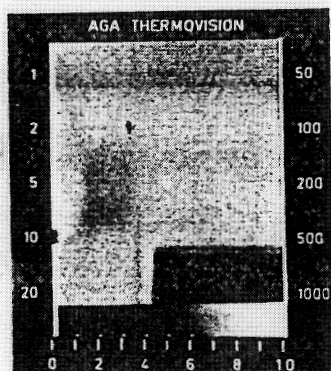
100 mm mineralull och 30 mm cellplast /
100 mm mineral wool and 30 mm cellular plastic

Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 26^\circ\text{C}$

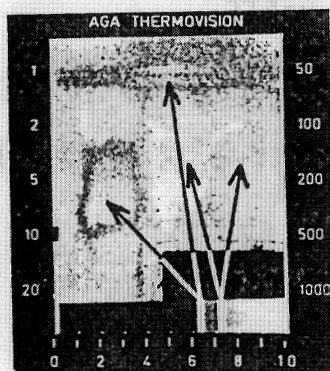
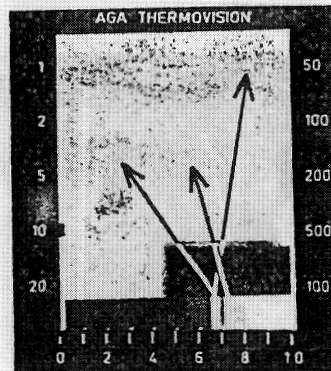
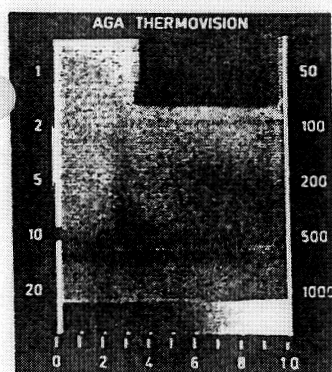
Tryckskillnad (inne – ute) /
Difference in preasure (indoors – outdoors): $p_i - p_u = +50\text{ N/m}^2$



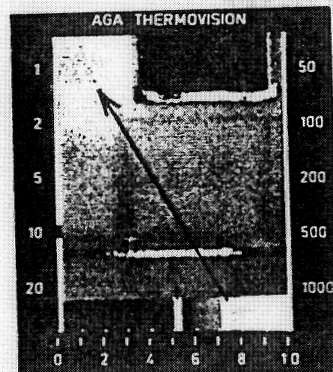
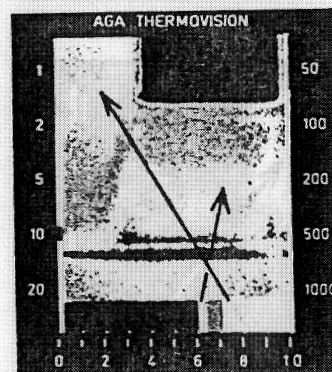
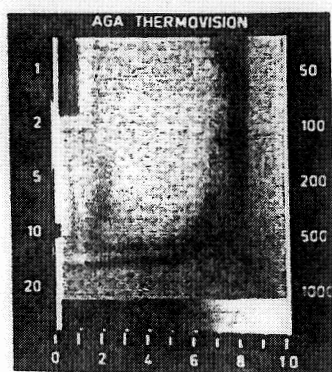
A1

A2 $\Delta t = 3.8^\circ\text{C}$ A3 $\Delta t = 3.3^\circ\text{C}$ 

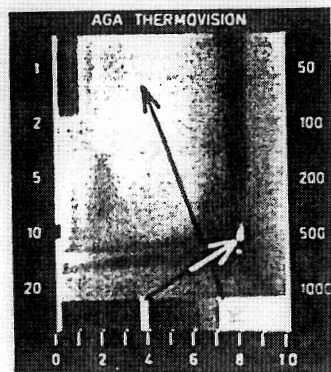
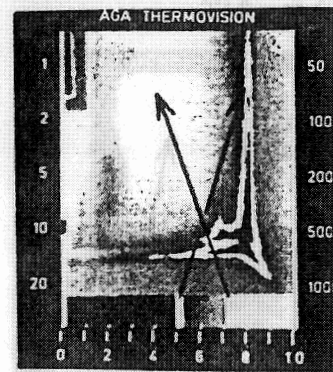
B1

B2 $\Delta t = 1.4^\circ\text{C}$ B3 $\Delta t = 0.8^\circ\text{C}$ 

C1

C2 $\Delta t = 3.3^\circ\text{C}$ C3 $\Delta t = 1.6^\circ\text{C}$ 

D1

D2 $\Delta t = 5.8^\circ\text{C}$ D3 $\Delta t = 3.4^\circ\text{C}$

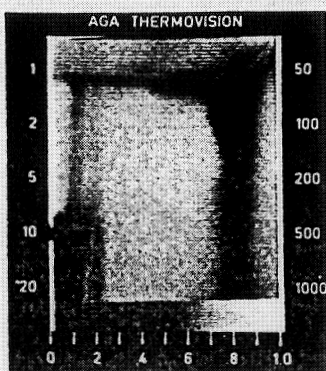
Regelv gg nr 2 / Framed cladding panel No. 2

Konstruktion med inbyggda fel / Design with deliberate faults

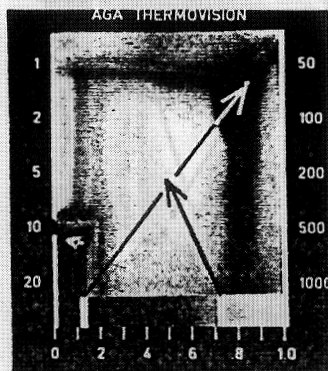
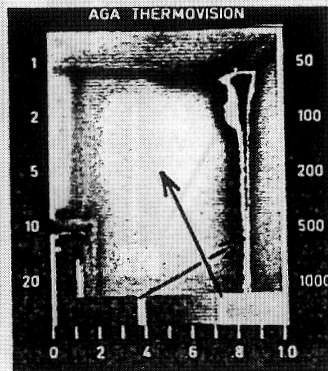
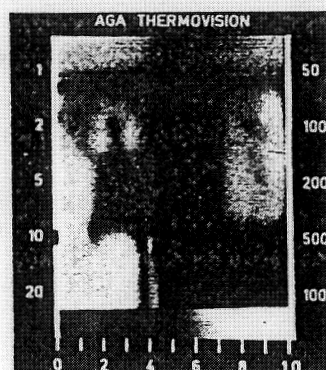
100 mm mineralull och 30 mm cellplast /
100 mm mineral wool and 30 mm cellular plastic

Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 26^\circ\text{C}$

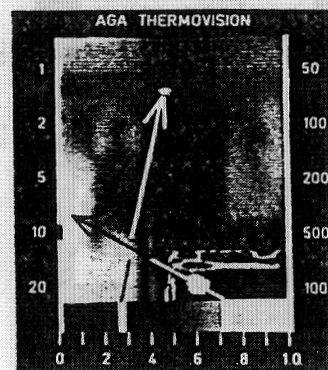
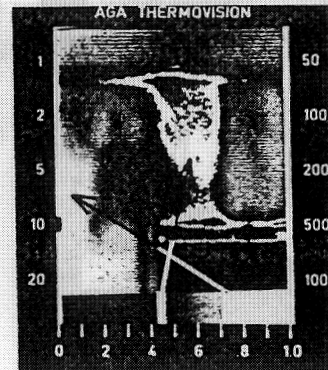
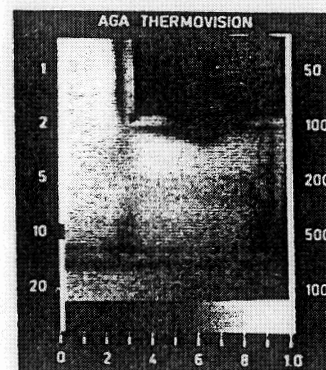
Tryckskillnad (inne – ute) /
Difference in pressure (indoors – outdoors): $p_i - p_u = -50\text{ N/m}^2$



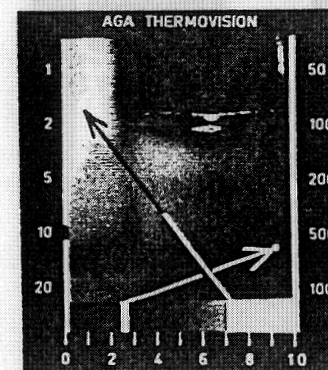
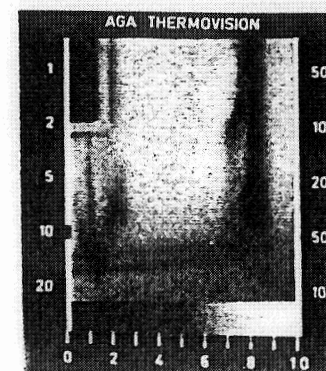
A1

A2 $\Delta t = 10.9^\circ\text{C}$ A3 $\Delta t = 5.7^\circ\text{C}$ 

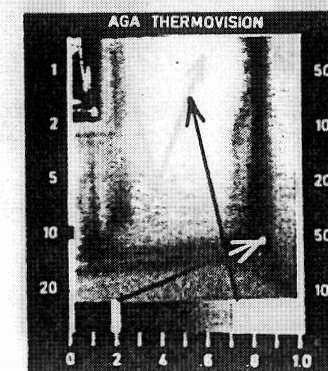
B1

B2 $\Delta t = 7.8^\circ\text{C}$ B3 $\Delta t = 3.6^\circ\text{C}$ 

C1

C2 $\Delta t = 8.1^\circ\text{C}$ 

D1

D2 $\Delta t = 9.4^\circ\text{C}$

Temperaturskillnad (inne – ute) /

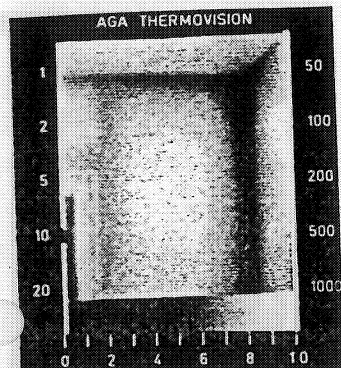
Difference in temperature (indoors – outdoors): $t_i - t_u = 11^\circ\text{C}$

Tryckskillnad (inne – ute) /

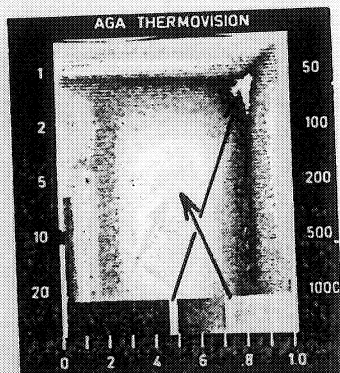
Difference in pressure (indoors – outdoors): $p_i - p_u = 0 \text{ N/m}^2$

A4, B4, C4, D4

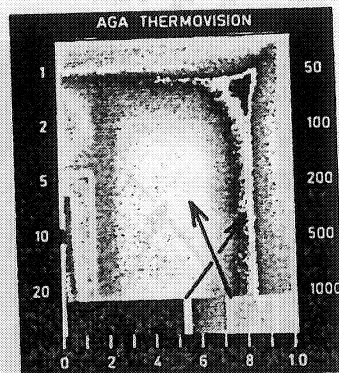
vit/white	19.9 – 20.5°C
gul/yellow	19.2 – 19.8°C
röd/red	18.5 – 19.1°C
violett/purple	17.7 – 18.4°C
ljusgrön/light green	17.0 – 17.6°C
mörkgrön/dark green	16.2 – 16.9°C
ljusblå/light blue	15.4 – 16.1°C
mörkblå/dark blue	14.5 – 15.3°C



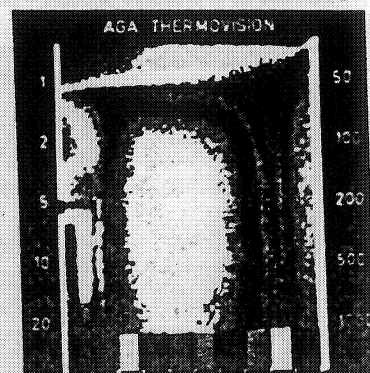
A1



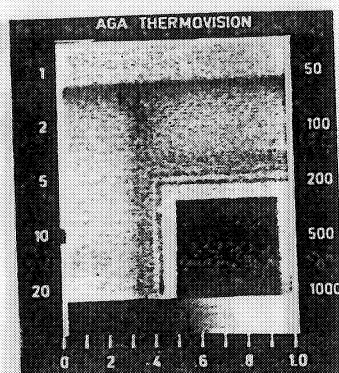
A2 $\Delta t = 3.6^\circ\text{C}$



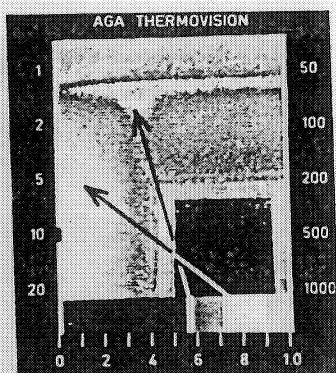
A3 $\Delta t = 2.5^\circ\text{C}$



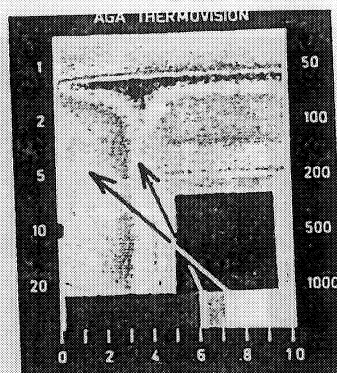
A4



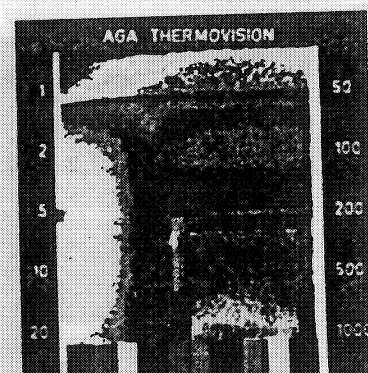
B1



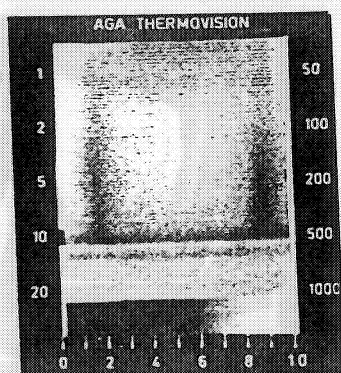
B2 $\Delta t = 2.1^\circ\text{C}$



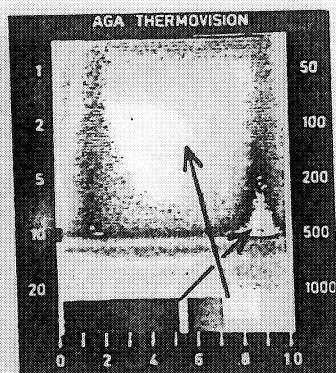
B3 $\Delta t = 1.4^\circ\text{C}$



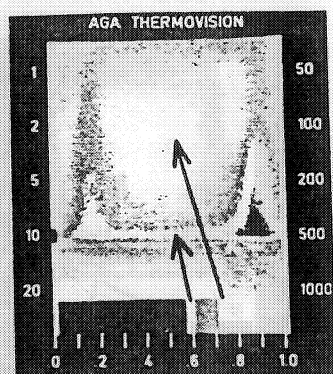
B4



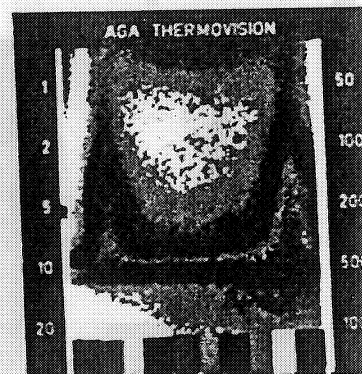
C1



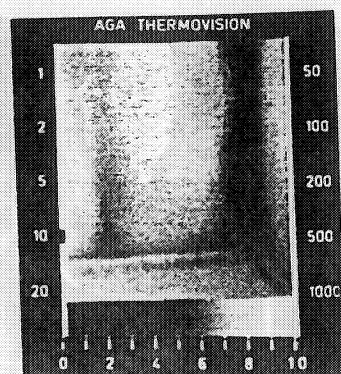
C2 $\Delta t = 2.7^\circ\text{C}$



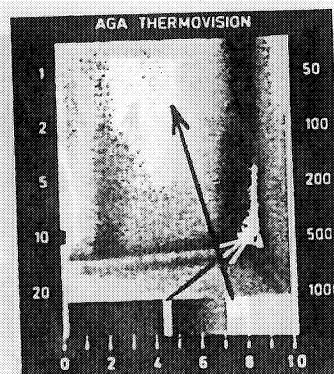
C3 $\Delta t = 1.9^\circ\text{C}$



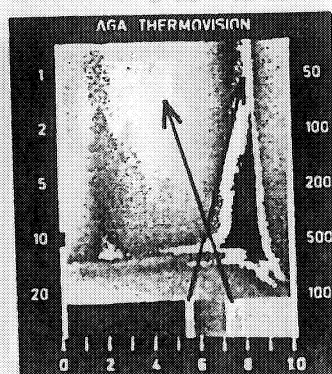
C4



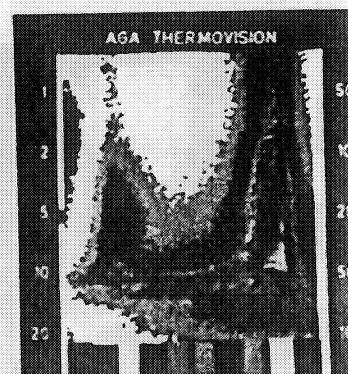
D1



D2 $\Delta t = 4.2^\circ\text{C}$



D3 $\Delta t = 2.4^\circ\text{C}$

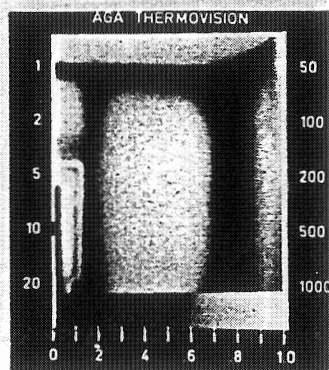


D4

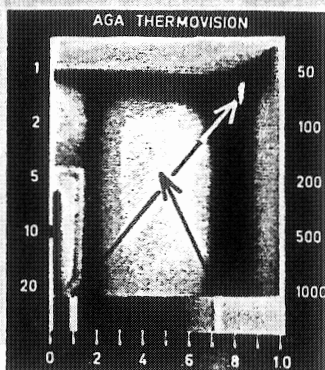
Temperaturskillnad (inne – ute) /
 Difference in temperature (indoors – outdoors): $t_i - t_u = 26^\circ\text{C}$

Tryckskillnad (inne – ute) /
 Difference in pressure (indoors – outdoors): $p_i - p_u = 0 \text{ N/m}^2$

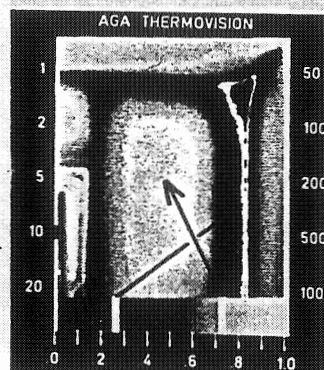
A4, B4, C4, D4	
vit/white	18.7 – 20.1°C
gul/yellow	17.3 – 18.6°C
röd/red	15.7 – 17.2°C
violett/purple	14.0 – 15.6°C
ljusgrön/light green	12.3 – 13.9°C
mörkgrön/dark green	10.5 – 12.2°C
ljusblå/light blue	8.6 – 10.4°C
mörkblå/dark blue	6.6 – 8.5°C



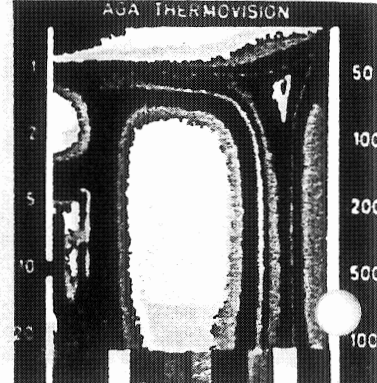
A1



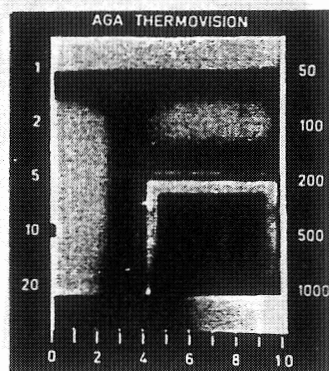
A2 $\Delta t = 10.0^\circ\text{C}$



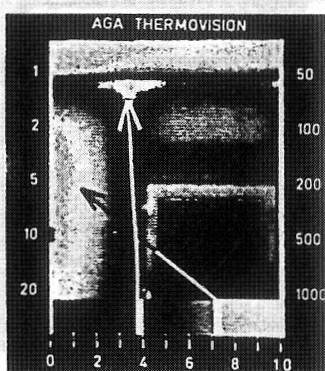
A3 $\Delta t = 7.2^\circ\text{C}$



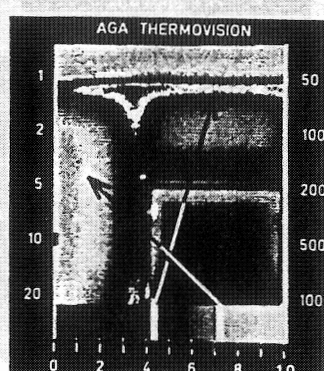
A4



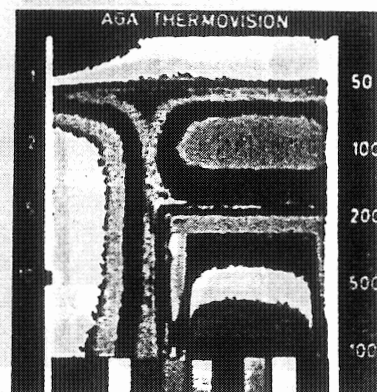
B1



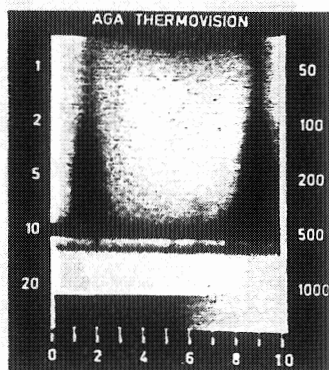
B2 $\Delta t = 5.1^\circ\text{C}$



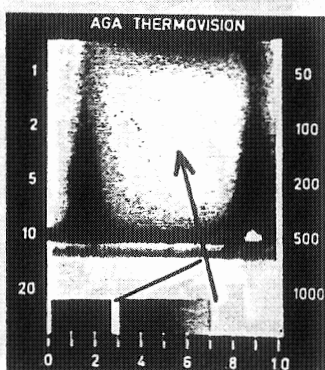
B3 $\Delta t = 4.4^\circ\text{C}$



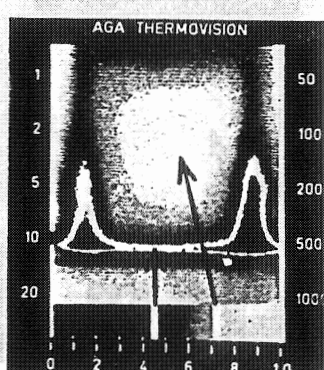
B4



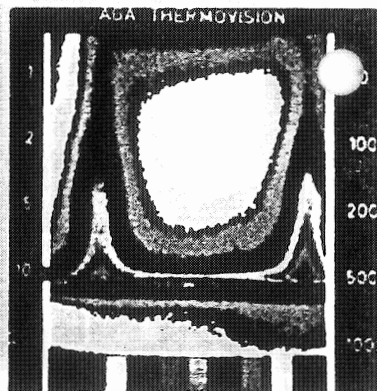
C1



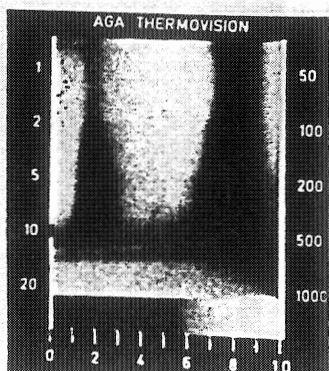
C2 $\Delta t = 6.7^\circ\text{C}$



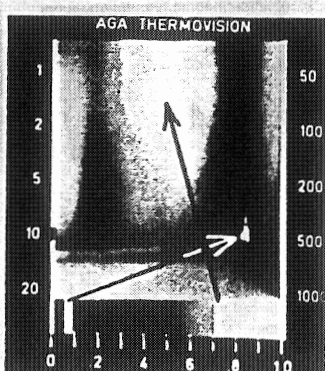
C3 $\Delta t = 4.1^\circ\text{C}$



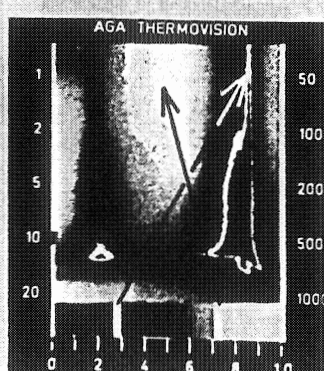
C4



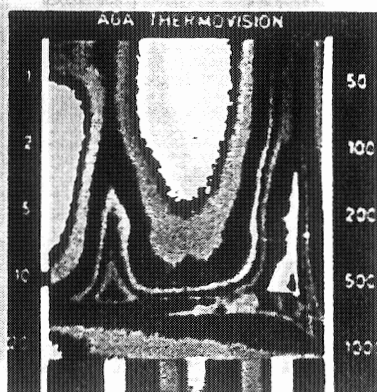
D1



D2 $\Delta t = 10.8^\circ\text{C}$



D3 $\Delta t = 6.9^\circ\text{C}$

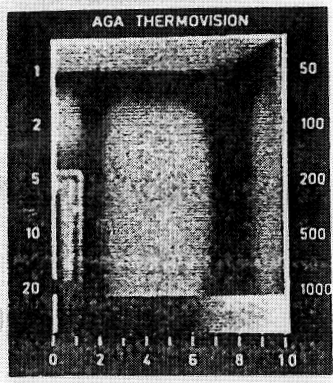


D4

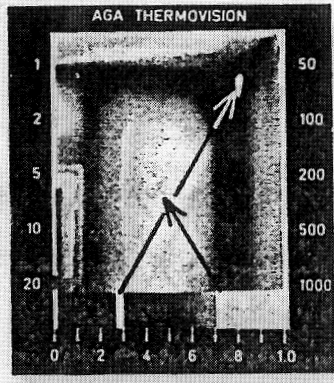
Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 41^{\circ}\text{C}$

Tryckskillnad (inne – ute) /
Difference in pressure (indoors – outdoors): $p_i - p_u = 0 \text{ N/m}^2$

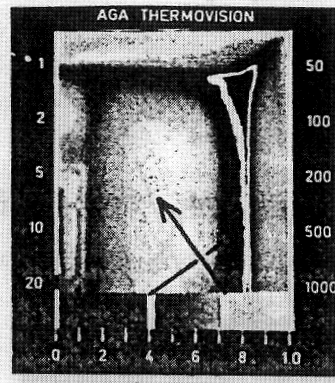
A4, B4, C4, D4	
vit/white	17.1 – 20.0°C
gul/yellow	13.7 – 17.0°C
röd/red	10.1 – 13.6°C
violett/purple	6.2 – 10.0°C
ljusgrön/light green	1.8 – 6.1°C
mörkgrön/dark green	- 3.0 – 1.7°C
ljusblå/light blue	- 9.2 – -3.1°C
mörkblå/dark blue	-16.5 – -9.1°C



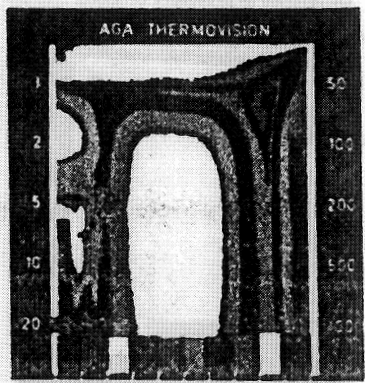
A1



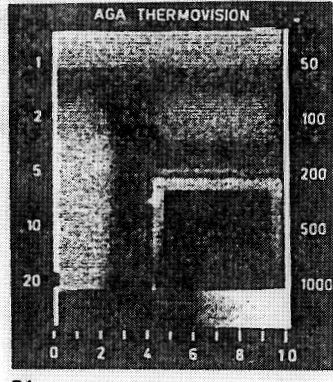
A2 $\Delta t = 15.5^{\circ}\text{C}$



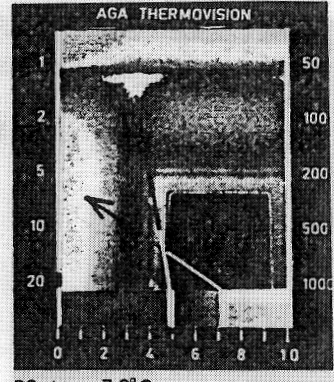
A3 $\Delta t = 10.4^{\circ}\text{C}$



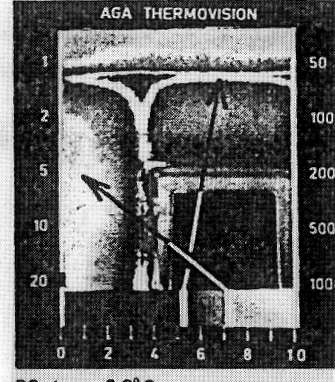
A4



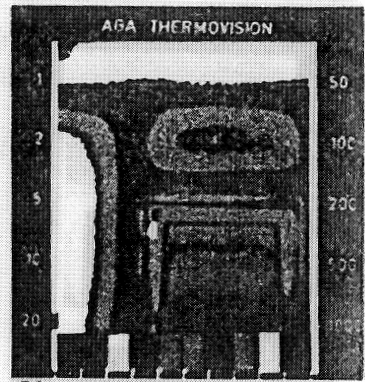
B1



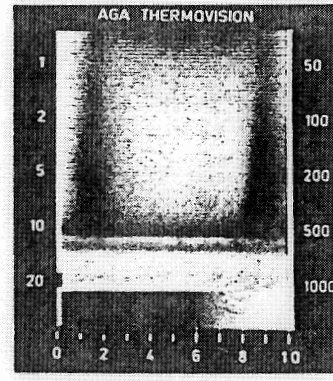
B2 $\Delta t = 7.3^{\circ}\text{C}$



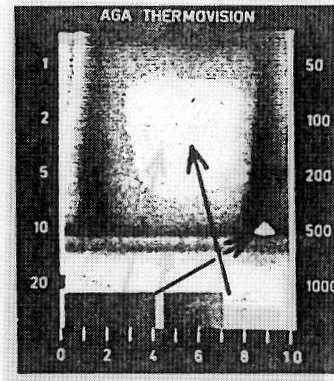
B3 $\Delta t = 6.3^{\circ}\text{C}$



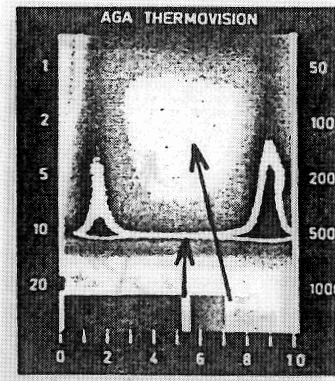
B4



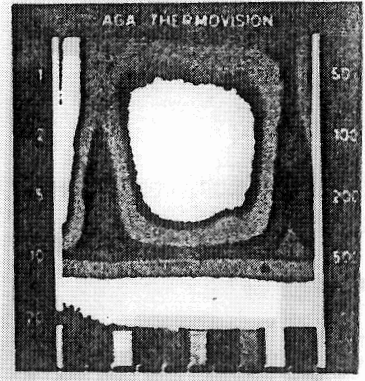
C1



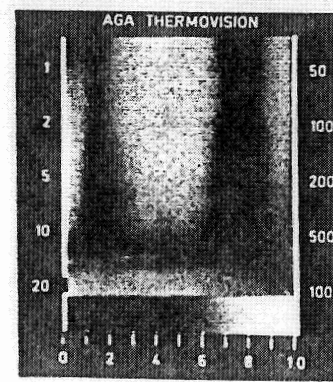
C2 $\Delta t = 10.5^{\circ}\text{C}$



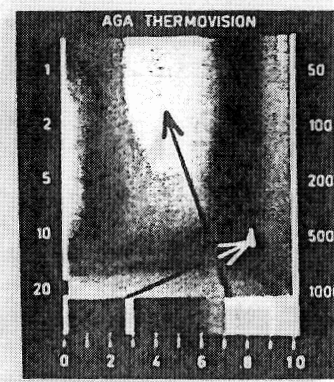
C3 $\Delta t = 6.0^{\circ}\text{C}$



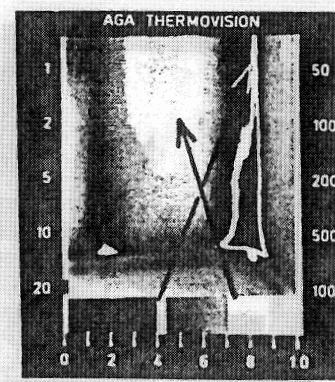
C4



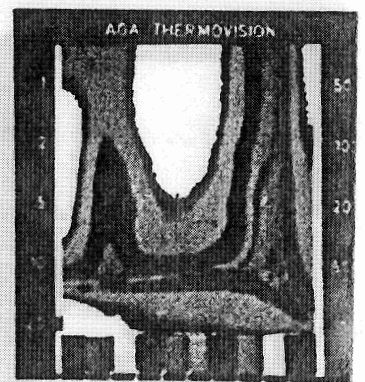
D1



D2 $\Delta t = 15.9^{\circ}\text{C}$



D3 $\Delta t = 10.4^{\circ}\text{C}$



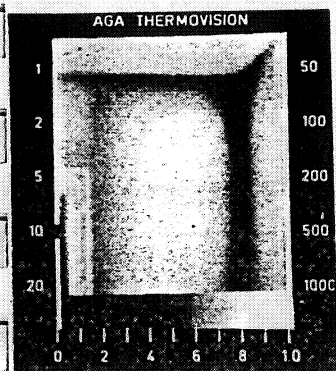
D4

Temperaturskillnad (inne – ute) /

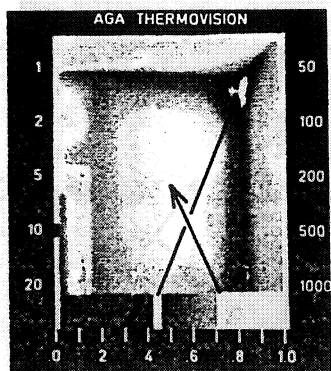
Difference in temperature (indoors – outdoors): $t_i - t_u = 11^\circ\text{C}$

Tryckskillnad (inne – ute) /

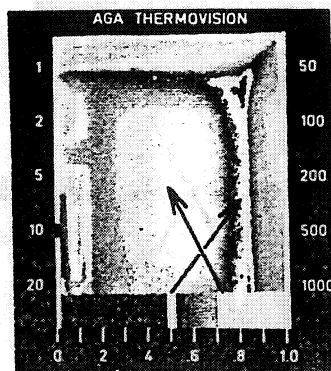
Difference in pressure (indoors – outdoors): $p_i - p_u = 0 \text{ N/m}^2$



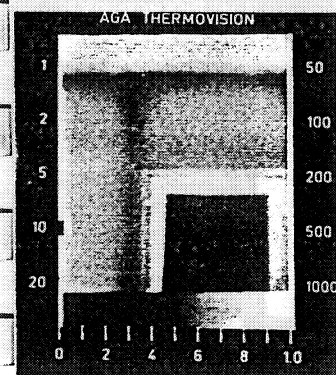
A1



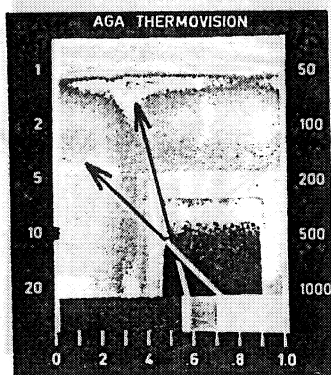
A2 $\Delta t = 4.1^\circ\text{C}$



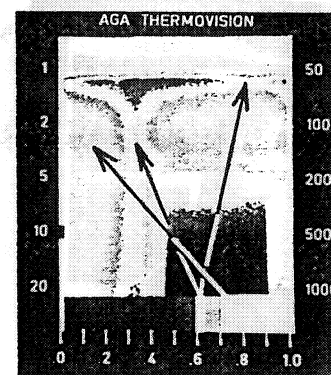
A3 $\Delta t = 3.1^\circ\text{C}$



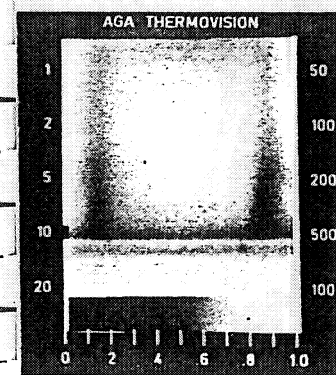
B1



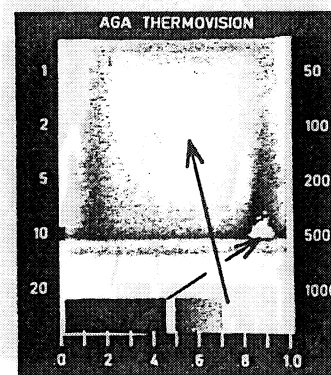
B2 $\Delta t = 2.2^\circ\text{C}$



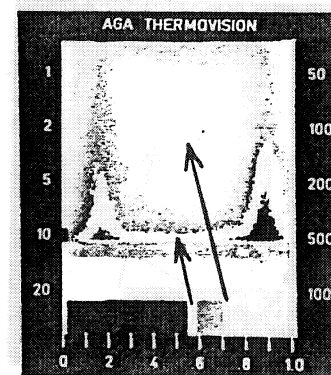
B3 $\Delta t = 1.4^\circ\text{C}$



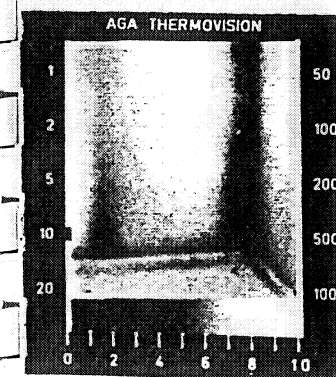
C1



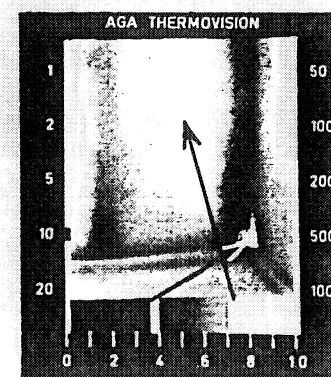
C2 $\Delta t = 3.6^\circ\text{C}$



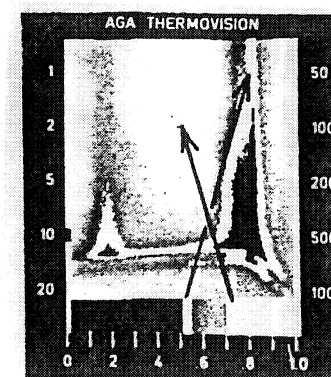
C3 $\Delta t = 2.1^\circ\text{C}$



D1



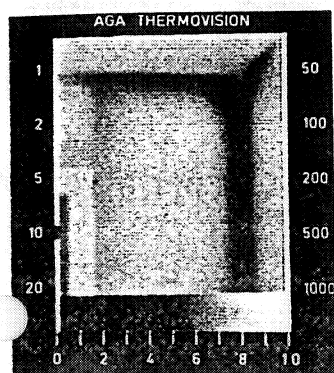
D2 $\Delta t = 5.0^\circ\text{C}$



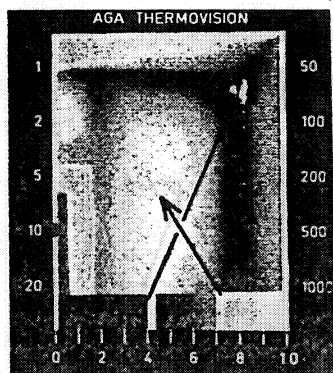
D3 $\Delta t = 2.8^\circ\text{C}$

Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 11^\circ\text{C}$

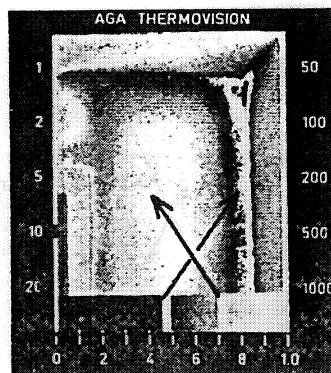
Tryckskillnad (inne – ute) /
Difference in pressure (indoors – outdoors): $p_i - p_u = +50 \text{ N/m}^2$



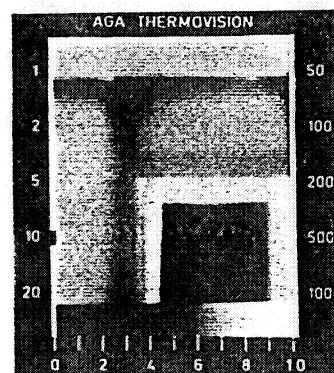
A1



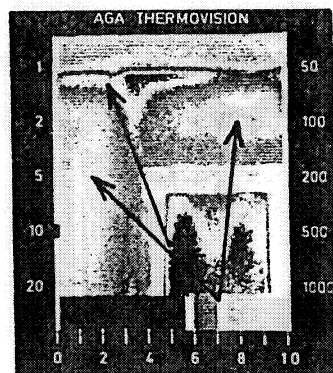
A2 $\Delta t = 4.5^\circ\text{C}$



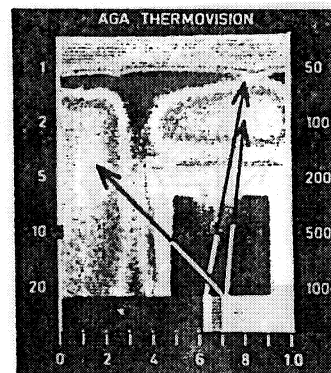
A3 $\Delta t = 3.3^\circ\text{C}$



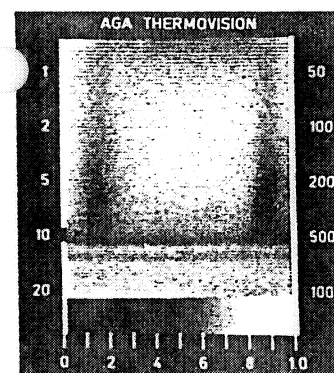
B1



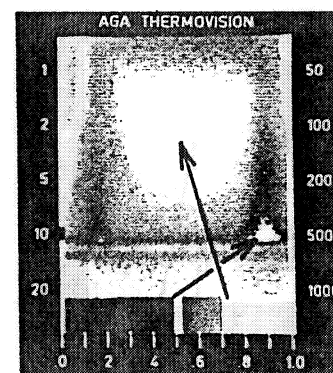
B2 $\Delta t = 1.9^\circ\text{C}$



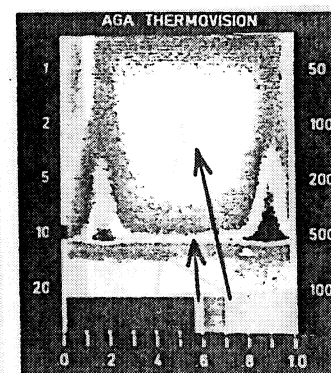
B3 $\Delta t = 1.2^\circ\text{C}$



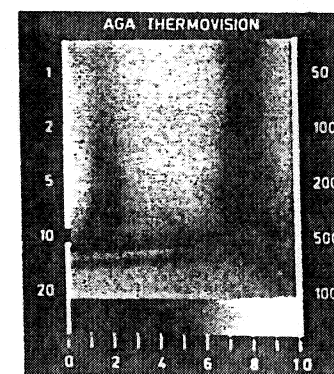
C1



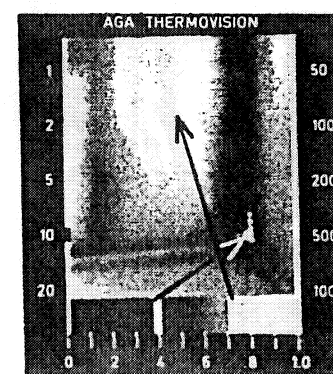
C2 $\Delta t = 3.9^\circ\text{C}$



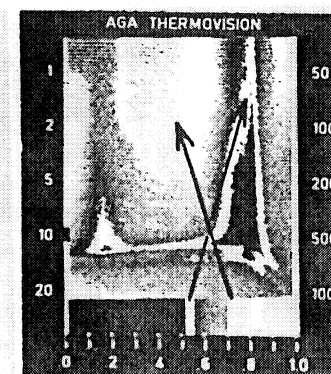
C3 $\Delta t = 2.4^\circ\text{C}$



D1



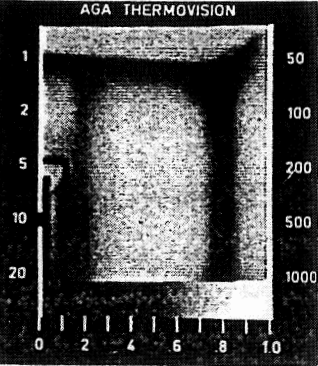
D2 $\Delta t = 4.9^\circ\text{C}$



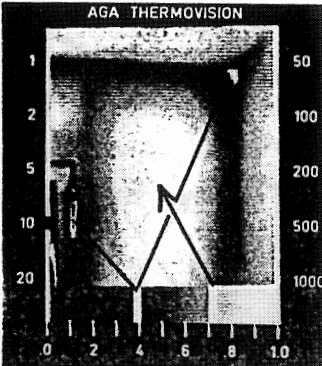
D3 $\Delta t = 2.7^\circ\text{C}$

Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 11^\circ\text{C}$

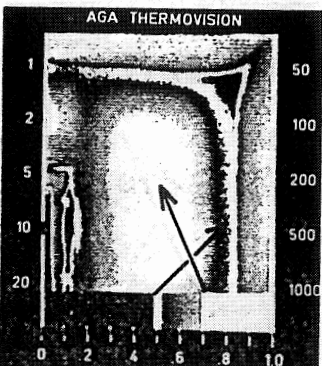
Tryckskillnad (inne – ute) /
Difference in preasure (indoors – outdoors): $p_i - p_u = -50\text{ N/m}^2$



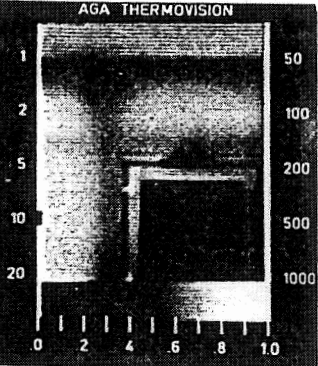
A1



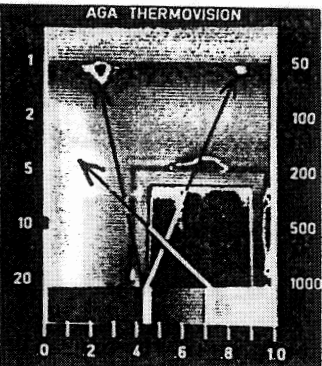
A2 $\Delta t = 4.9^\circ\text{C}$



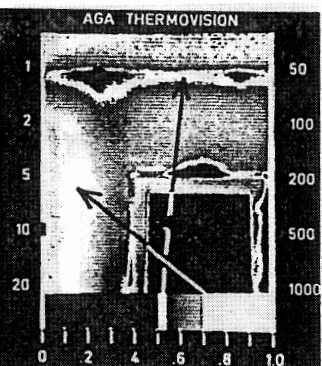
A3 $\Delta t = 3.0^\circ\text{C}$



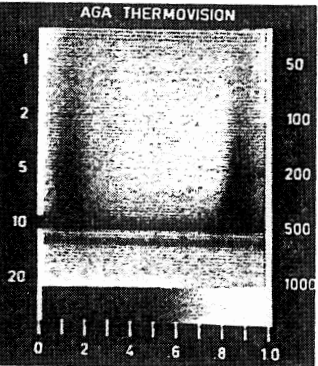
B1



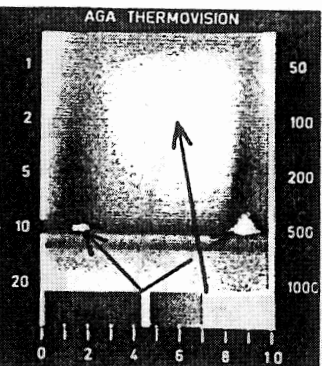
B2 $\Delta t = 4.1^\circ\text{C}$



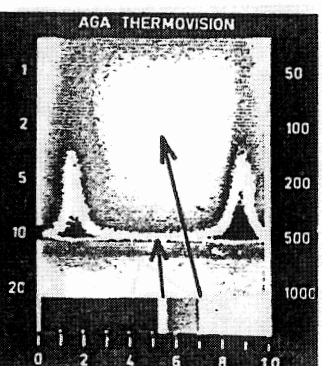
B3 $\Delta t = 2.8^\circ\text{C}$



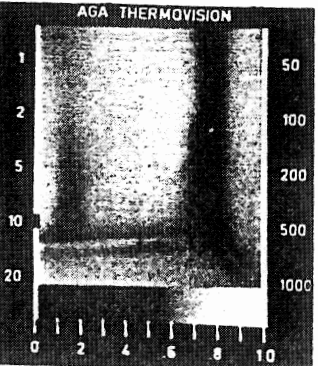
C1



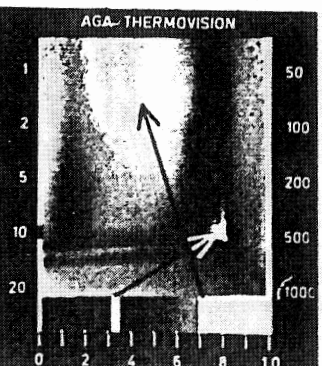
C2 $\Delta t = 3.9^\circ\text{C}$



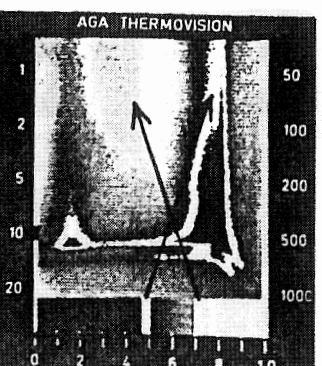
C3 $\Delta t = 2.4^\circ\text{C}$



D1



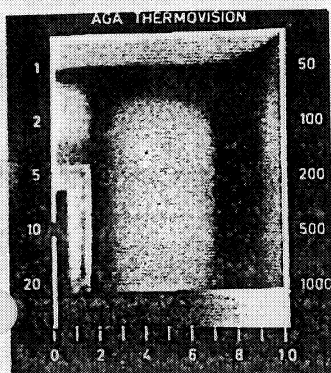
D2 $\Delta t = 5.9^\circ\text{C}$



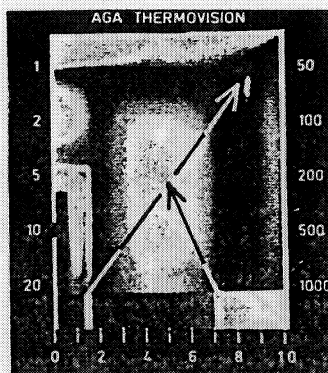
D3 $\Delta t = 3.2^\circ\text{C}$

Temperaturskillnad (inne – ute) /
 Difference in temperature (indoors – outdoors): $t_i - t_u = 26^\circ\text{C}$

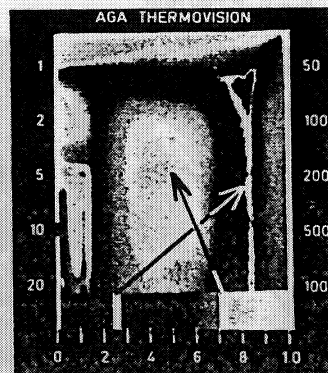
Tryckskillnad (inne – ute) /
 Difference in pressure (indoors – outdoors): $p_i - p_u = 0 \text{ N/m}^2$



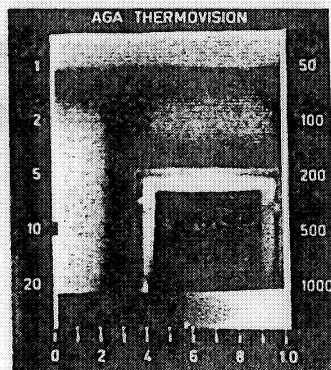
A1



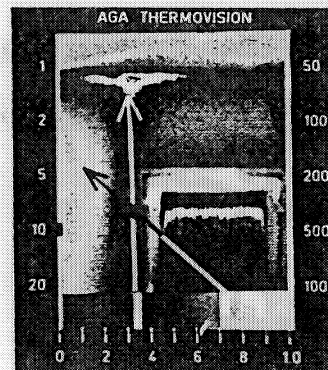
A2 $\Delta t = 9.5^\circ\text{C}$



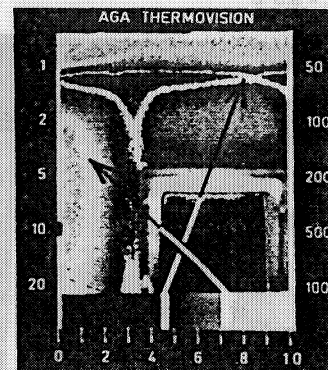
A3 $\Delta t = 7.5^\circ\text{C}$



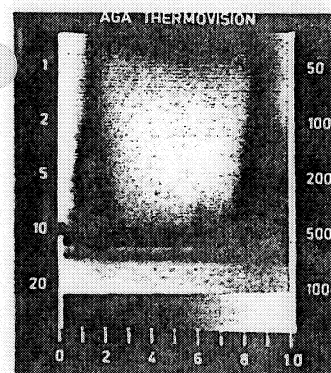
B1



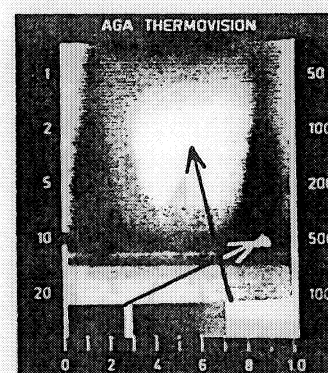
B2 $\Delta t = 6.0^\circ\text{C}$



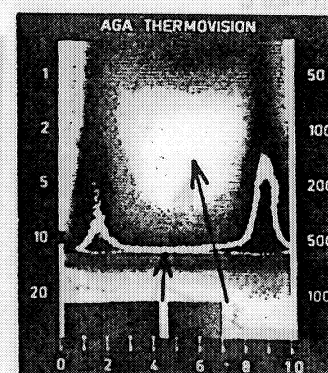
B3 $\Delta t = 3.8^\circ\text{C}$



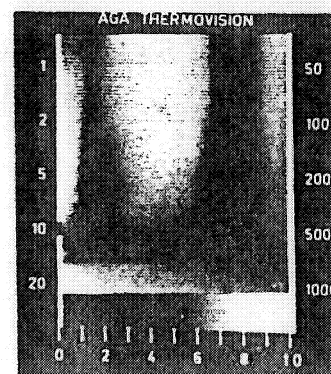
C1



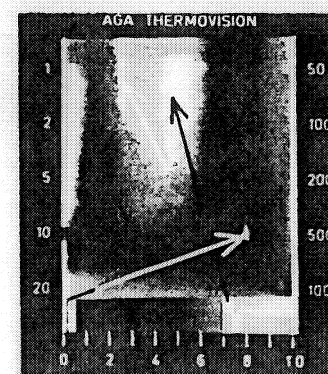
C2 $\Delta t = 6.9^\circ\text{C}$



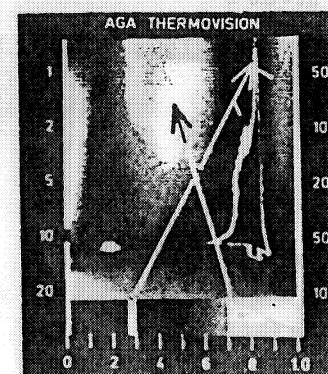
C3 $\Delta t = 4.2^\circ\text{C}$



D1



D2 $\Delta t = 11.7^\circ\text{C}$

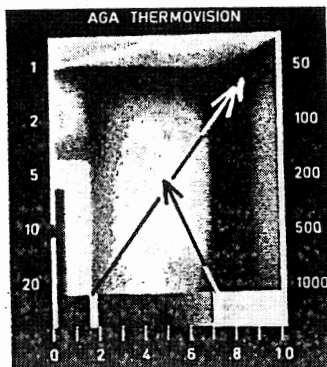
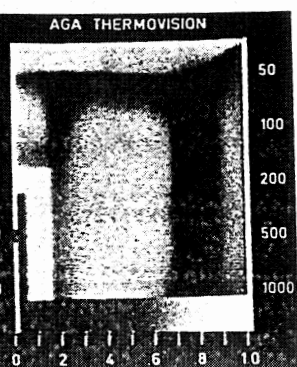
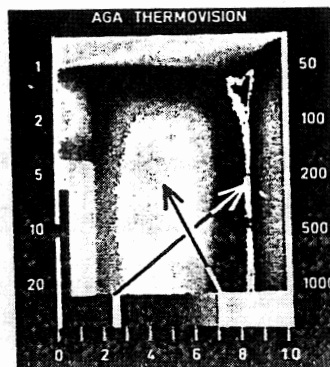
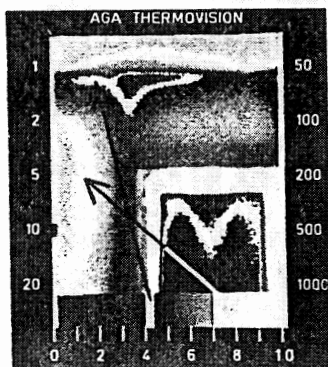
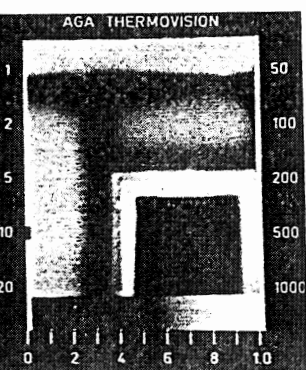
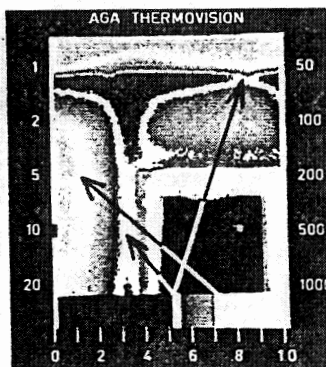
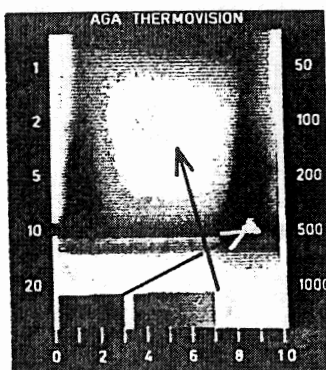
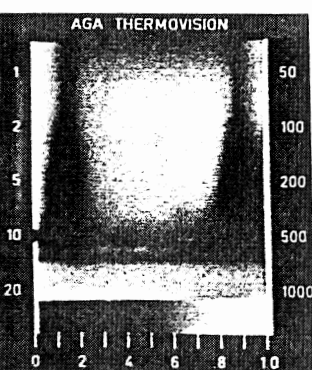
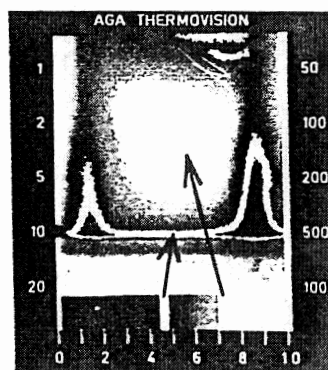
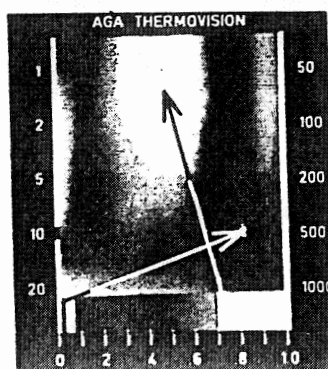
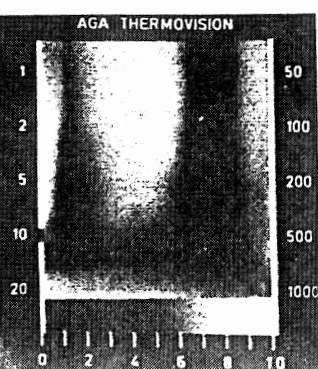
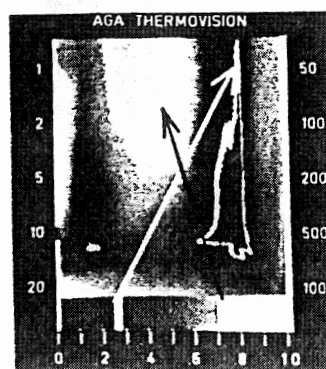


D3 $\Delta t = 7.0^\circ\text{C}$

Sandwichvägg / Sandwich wall unit
 Konstruktion med inbyggda fel / Design with deliberate faults

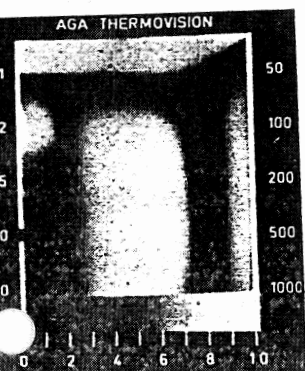
Temperaturskillnad (inne – ute) /
 Difference in temperature (indoors – outdoors): $t_i - t_u = 26^\circ\text{C}$

Tryckskillnad (inne – ute) /
 Difference in pressure (indoors – outdoors): $p_i - p_u = +50\text{ N/m}^2$

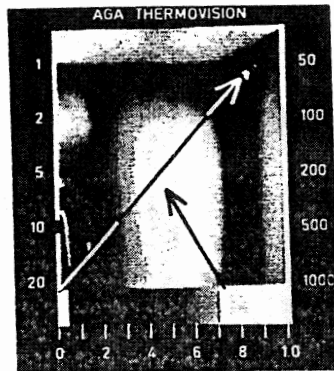
A2 $\Delta t = 9.0^\circ\text{C}$ A3 $\Delta t = 7.5^\circ\text{C}$ B2 $\Delta t = 4.6^\circ\text{C}$ B3 $\Delta t = 3.0^\circ\text{C}$ C2 $\Delta t = 6.6^\circ\text{C}$ C3 $\Delta t = 3.9^\circ\text{C}$ D2 $\Delta t = 11.5^\circ\text{C}$ D3 $\Delta t = 7.1^\circ\text{C}$

Temperaturskillnad (inne – ute) /
 Difference in temperature (indoors – outdoors): $t_i - t_u = 26^\circ\text{C}$

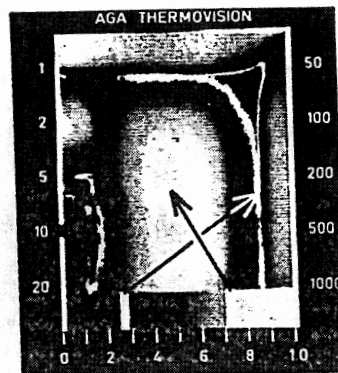
Tryckskillnad (inne – ute) /
 Difference in pressure (indoors – outdoors): $p_i - p_u = -50\text{ N/m}^2$



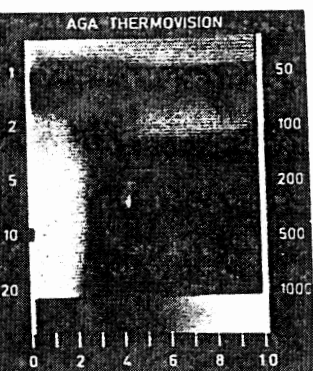
D1



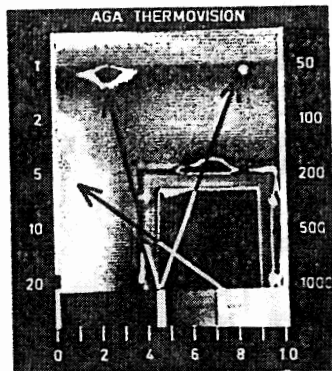
A2 $\Delta t = 12.1^\circ\text{C}$



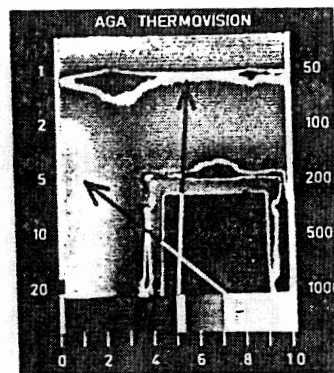
A3 $\Delta t = 7.3^\circ\text{C}$



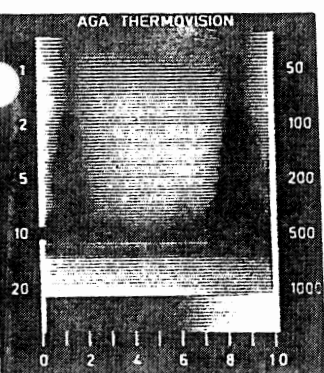
B1



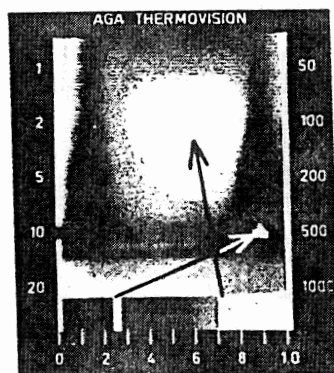
B2 $\Delta t = 8.4^\circ\text{C}$



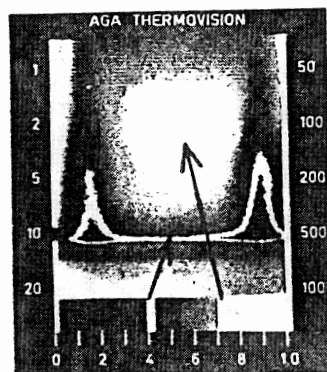
B3 $\Delta t = 6.4^\circ\text{C}$



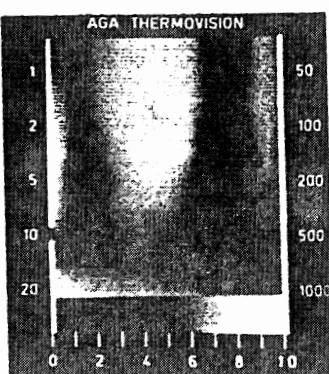
C1



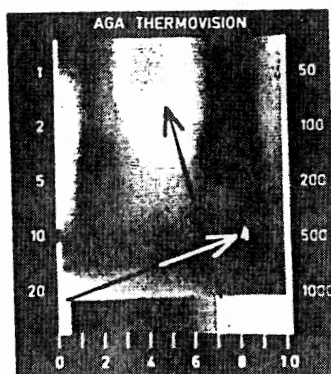
C2 $\Delta t = 7.4^\circ\text{C}$



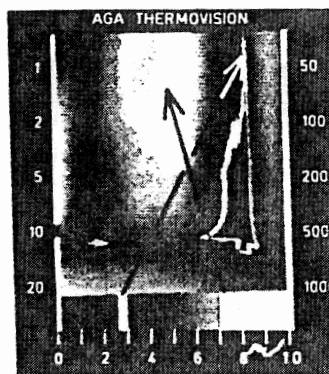
C3 $\Delta t = 4.7^\circ\text{C}$



D2



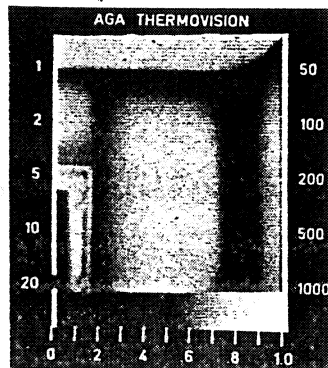
D2 $\Delta t = 11.9^\circ\text{C}$



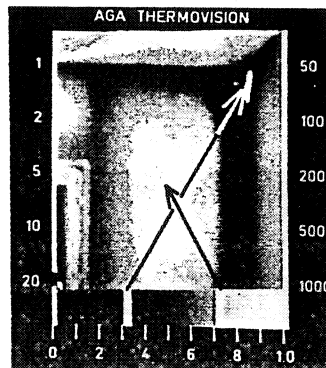
D3 $\Delta t = 7.0^\circ\text{C}$

Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 41^\circ\text{C}$

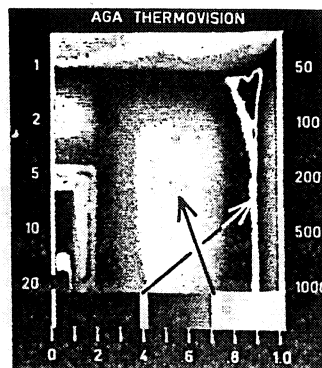
Tryckskillnad (inne – ute) /
Difference in preasure (indoors – outdoors): $p_i - p_u = 0 \text{ N/m}^2$



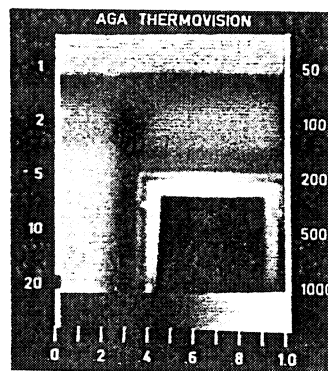
A1



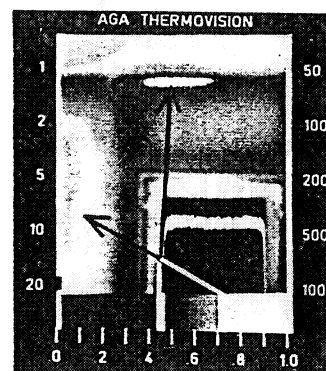
A2 $\Delta t = 13.8^\circ\text{C}$



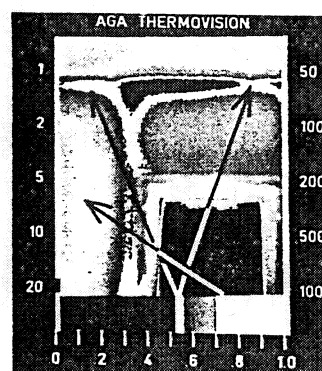
A3 $\Delta t = 10.6^\circ\text{C}$



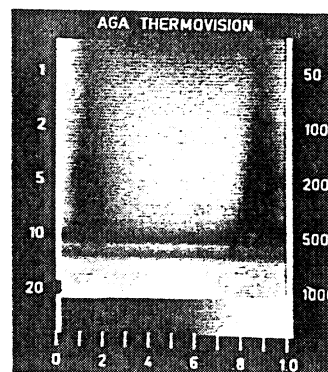
B1



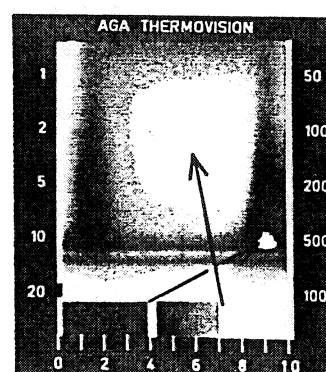
B2 $\Delta t = 8.7^\circ\text{C}$



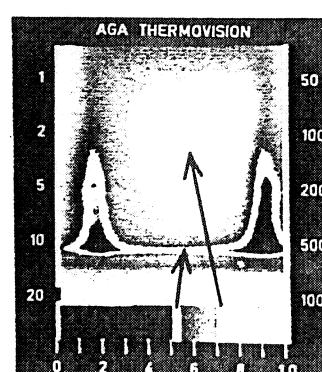
B3 $\Delta t = 6.0^\circ\text{C}$



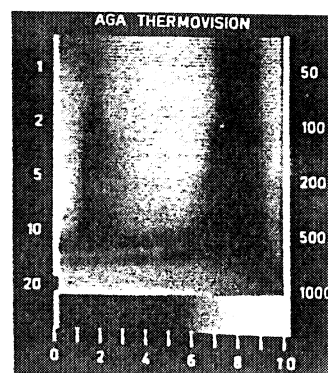
C1



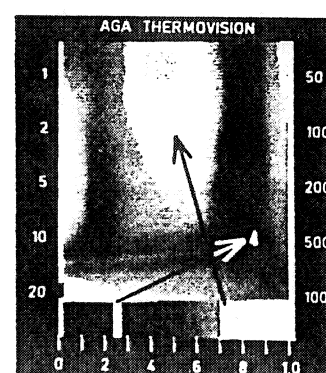
C2 $\Delta t = 10.8^\circ\text{C}$



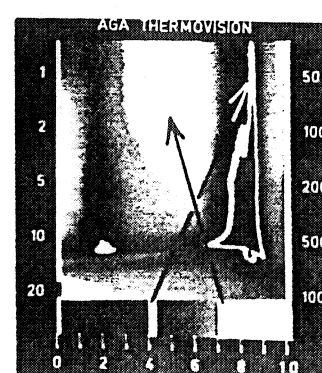
C3 $\Delta t = 6.3^\circ\text{C}$



D1



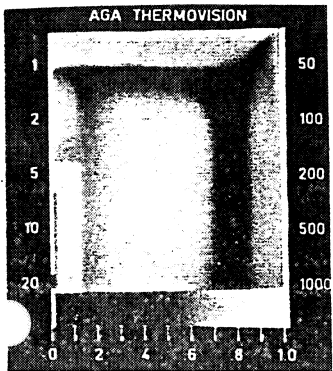
D2 $\Delta t = 17.8^\circ\text{C}$



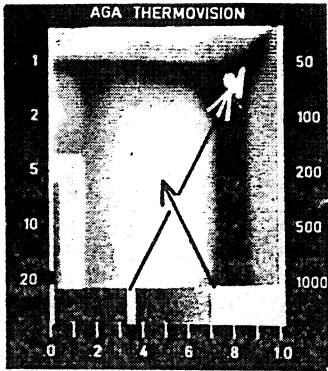
D3 $\Delta t = 10.5^\circ\text{C}$

Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 41^\circ\text{C}$

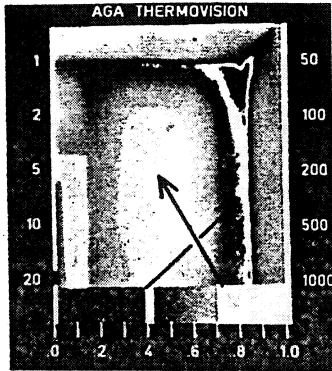
Tryckskillnad (inne – ute) /
Difference in pressure (indoors – outdoors): $p_i - p_u = +50\text{ N/m}^2$



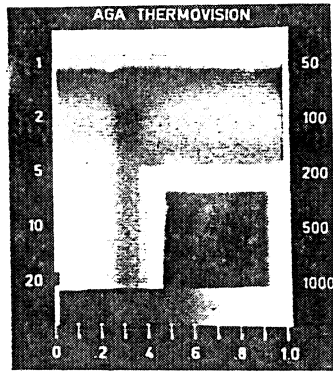
A1



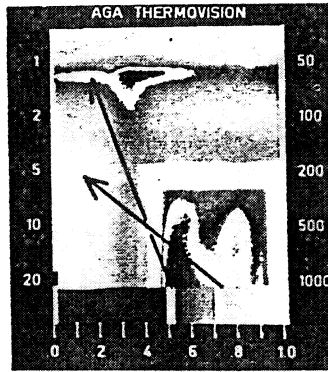
A2 $\Delta t = 12.9^\circ\text{C}$



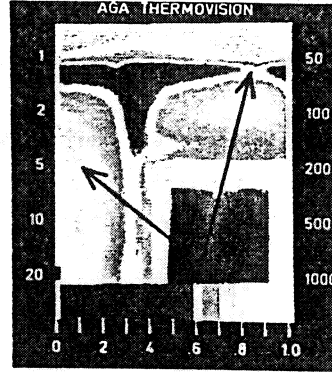
A3 $\Delta t = 10.6^\circ\text{C}$



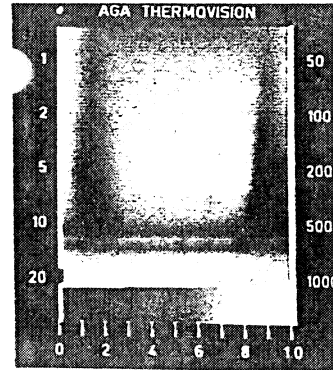
B1



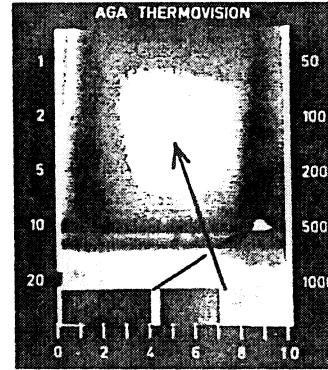
B2 $\Delta t = 6.9^\circ\text{C}$



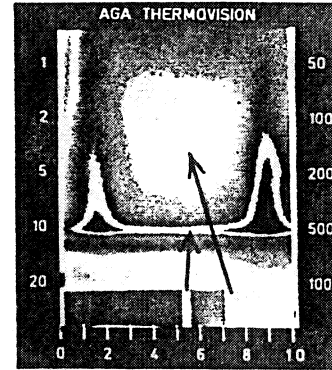
B3 $\Delta t = 3.4^\circ\text{C}$



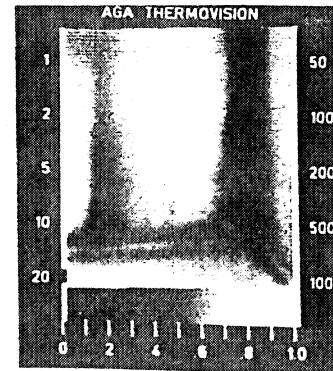
C1



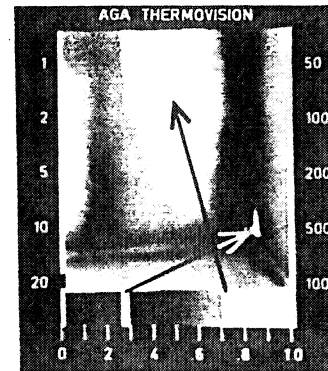
C2 $\Delta t = 10.5^\circ\text{C}$



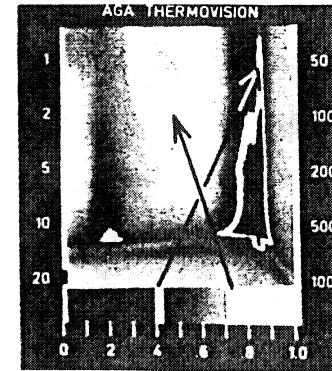
C3 $\Delta t = 5.8^\circ\text{C}$



D1



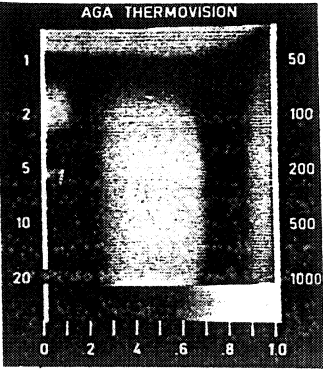
D2 $\Delta t = 16.1^\circ\text{C}$



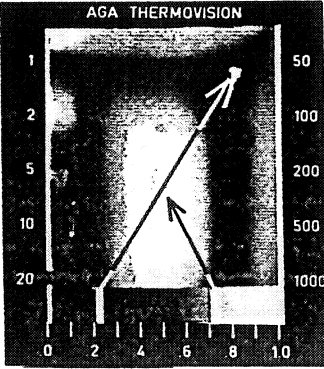
D3 $\Delta t = 10.6^\circ\text{C}$

Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 41^\circ\text{C}$

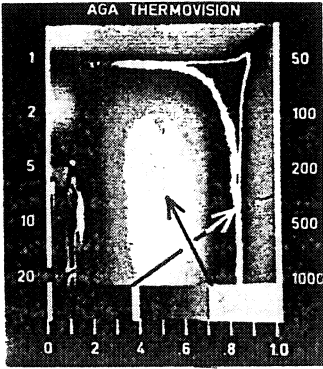
Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $p_i - p_u = -50 \text{ N/m}^2$



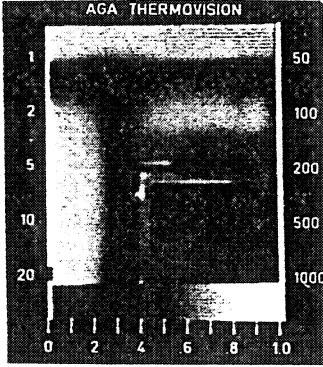
A1



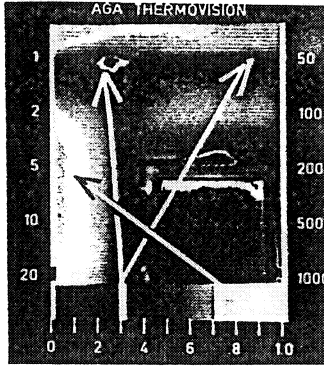
A2 $\Delta t = 18.9^\circ\text{C}$



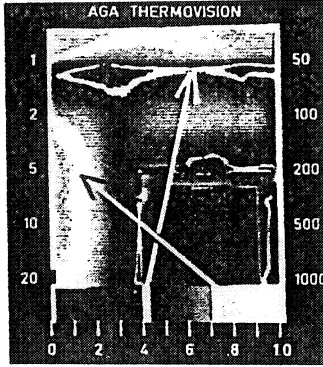
A3 $\Delta t = 11.5^\circ\text{C}$



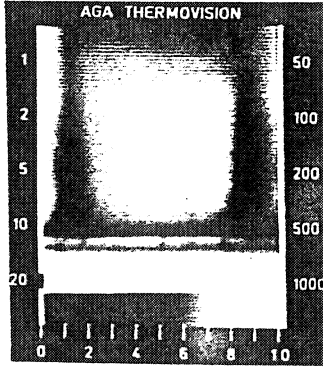
B1



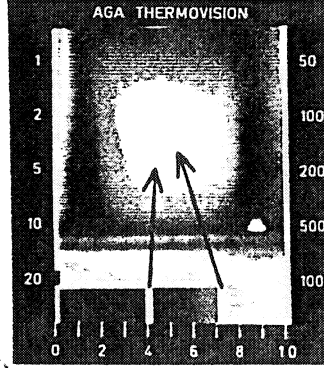
B2 $\Delta t = 22.0^\circ\text{C}$



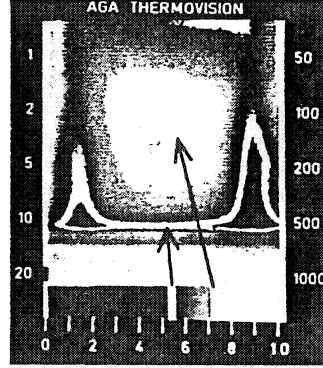
B3 $\Delta t = 10.5^\circ\text{C}$



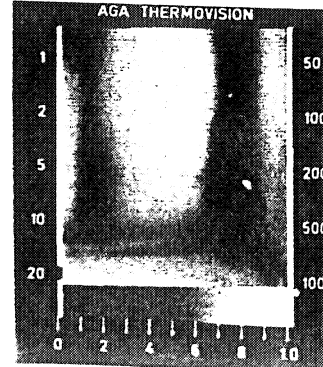
C1



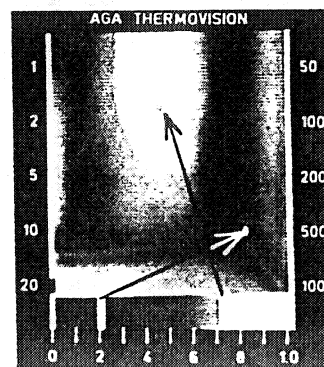
C2 $\Delta t = 10.8^\circ\text{C}$



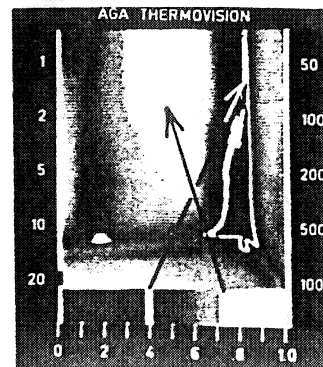
C3 $\Delta t = 6.0^\circ\text{C}$



D1



D2 $\Delta t = 19.6^\circ\text{C}$



D3 $\Delta t = 11.2^\circ\text{C}$

Temperaturskillnad (inne – ute) /

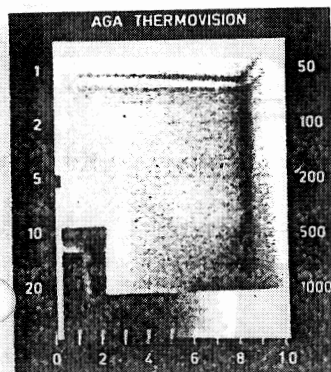
Difference in temperature (indoors – outdoors): $t_i - t_u = 11^\circ\text{C}$

Tryckskillnad (inne – ute) /

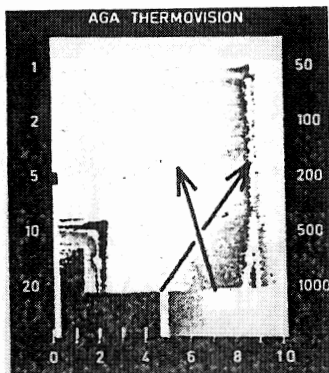
Difference in pressure (indoors – outdoors): $p_i - p_u = 0 \text{ N/m}^2$

A4, B4, C4, D4

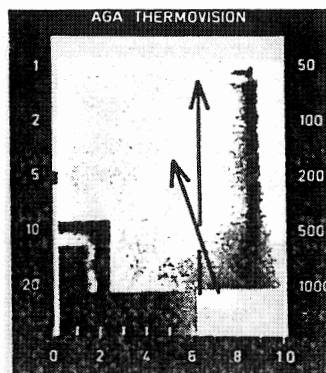
vit/white	20.4 – 21.1° C
gul/yellow	19.7 – 20.3° C
röd/red	18.8 – 19.6° C
violett/purple	18.0 – 18.7° C
ljusgrön/light green	17.2 – 17.9° C
mörkgrön/dark green	16.4 – 17.1° C
ljusblå/light blue	15.5 – 16.3° C
mörkblå/dark blue	14.5 – 15.4° C



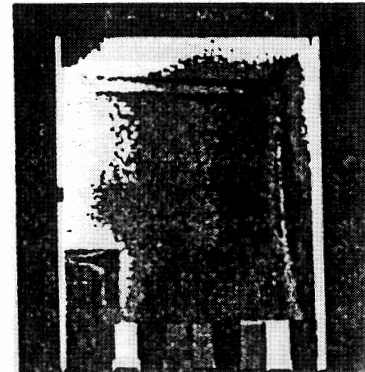
A1



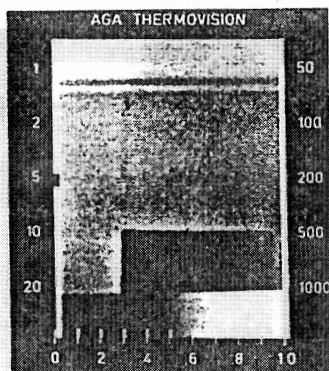
A2 $\Delta t = 1.7^\circ\text{C}$



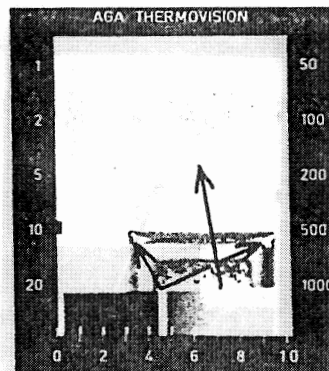
A3 $\Delta t = 0.6^\circ\text{C}$



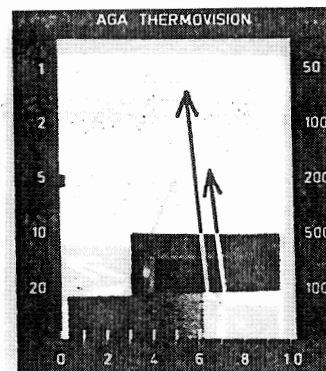
A4



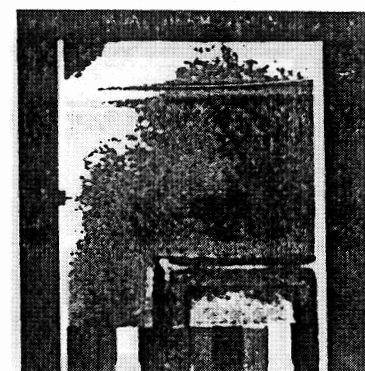
B1



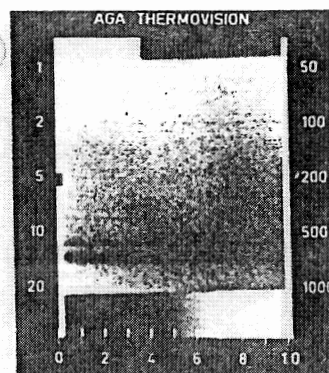
B2 $\Delta t = 4.1^\circ\text{C}$



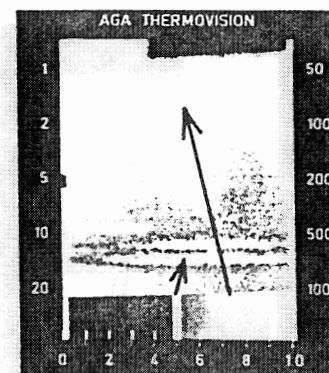
B3 $\Delta t = 0.6^\circ\text{C}$



B4



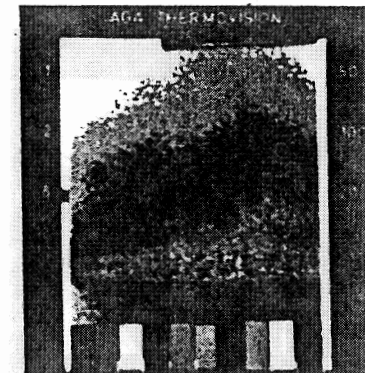
C1



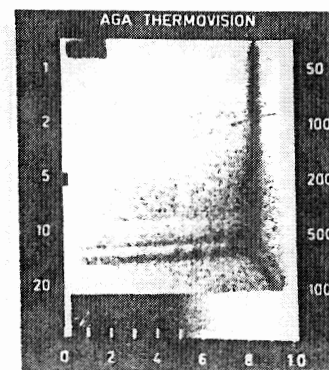
C2 $\Delta t = 1.6^\circ\text{C}$



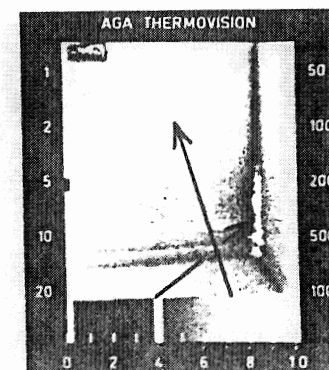
C3 $\Delta t = 1.7^\circ\text{C}$



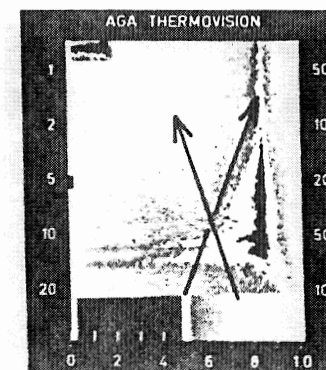
C4



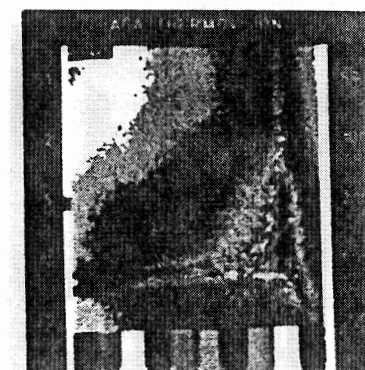
D1



D2 $\Delta t = 2.5^\circ\text{C}$



D3 $\Delta t = 1.7^\circ\text{C}$

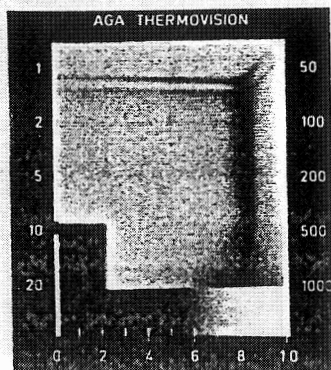


D4

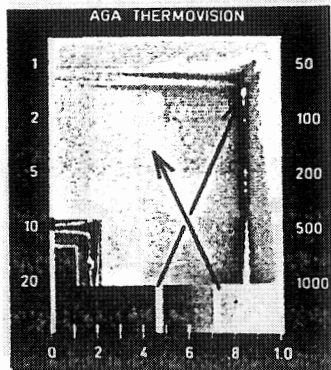
Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 26^\circ\text{C}$

Tryckskillnad (inne – ute) /
Difference in pressure (indoors – outdoors): $p_i - p_u = 0\text{ N/m}^2$

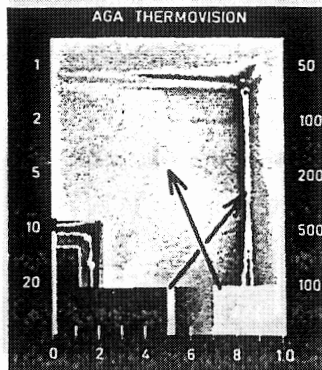
A4, B4, C4, D4	
vit/white	19.6 – 21.1°C
gul/yellow	18.0 – 19.5°C
röd/red	16.3 – 17.9°C
violett/purple	14.5 – 16.2°C
ljusgrön/light green	12.6 – 14.4°C
mörkgrön/dark green	10.6 – 12.5°C
ljusblå/light blue	8.5 – 10.5°C
mörkblå/dark blue	6.3 – 8.4°C



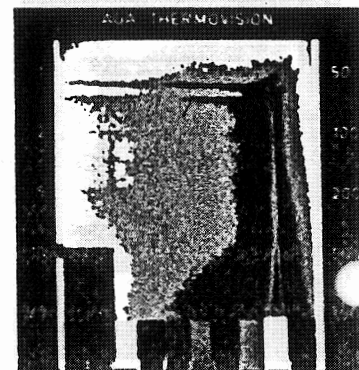
A1



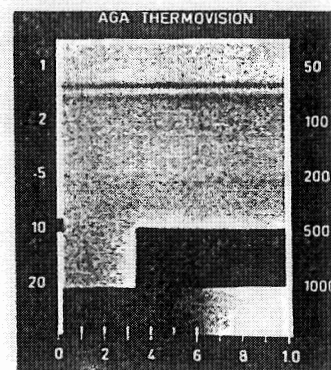
A2 $\Delta t = 4.4^\circ\text{C}$



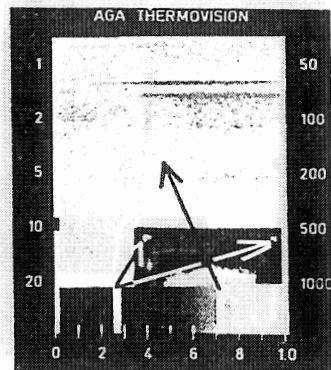
A3 $\Delta t = 3.5^\circ\text{C}$



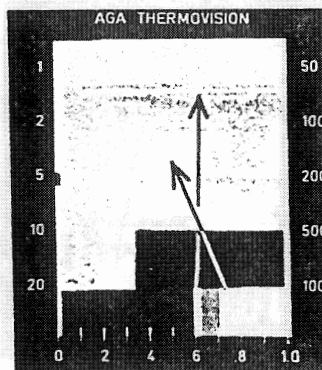
A4



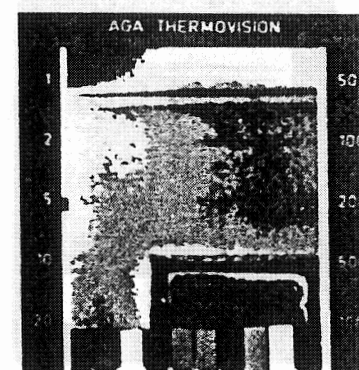
B1



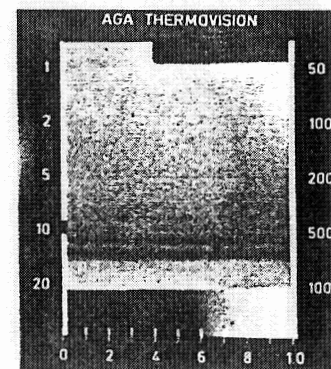
B2 $\Delta t = 8.0^\circ\text{C}$



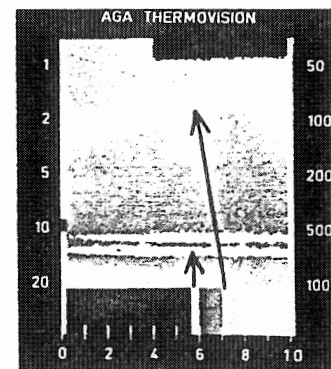
B3 $\Delta t = 0.9^\circ\text{C}$



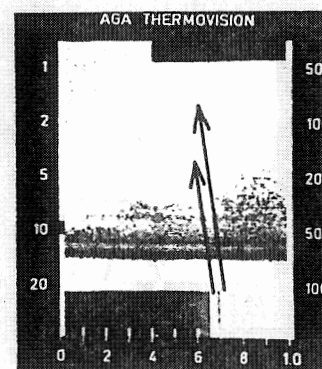
B4



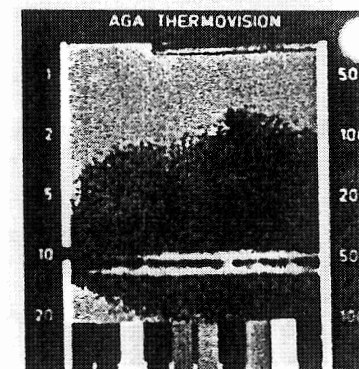
C1



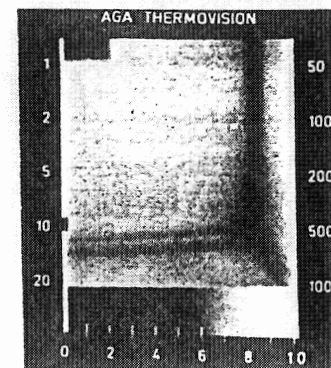
C2 $\Delta t = 2.1^\circ\text{C}$



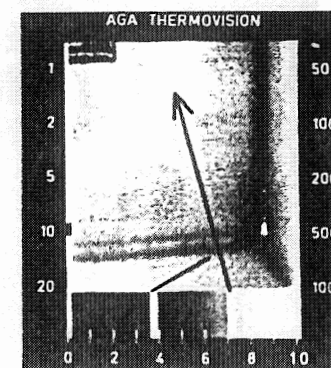
C3 $\Delta t = 0.6^\circ\text{C}$



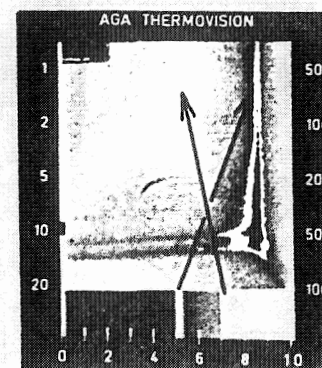
C4



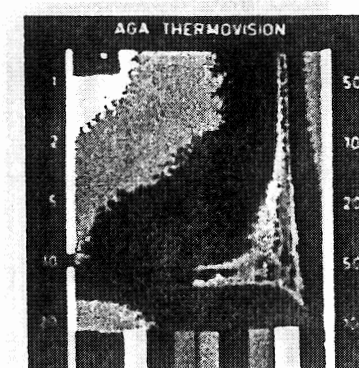
D1



D2 $\Delta t = 5.9^\circ\text{C}$



D3 $\Delta t = 3.5^\circ\text{C}$

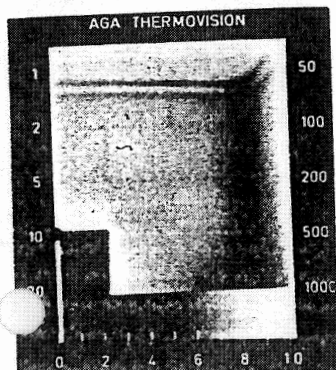


D4

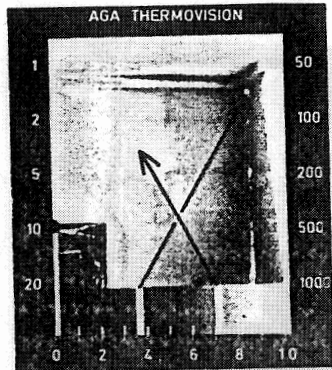
Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 41^\circ\text{C}$

Tryckskillnad (inne – ute) /
Difference in pressure (indoors – outdoors): $p_i - p_u = 0 \text{ N/m}^2$

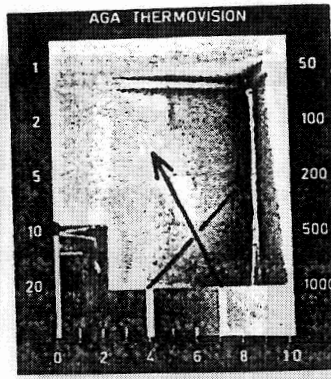
A4, B4, C4, D4	
vit/white	18.3 – 19.9°C
gul/yellow	16.6 – 18.2°C
röd/red	14.9 – 16.5°C
violett/purple	13.0 – 14.8°C
ljusgrön/light green	11.0 – 12.9°C
mörkgrön/dark green	8.9 – 10.9°C
ljusblå/light blue	6.7 – 8.8°C
mörkblå/dark blue	4.4 – 6.6°C



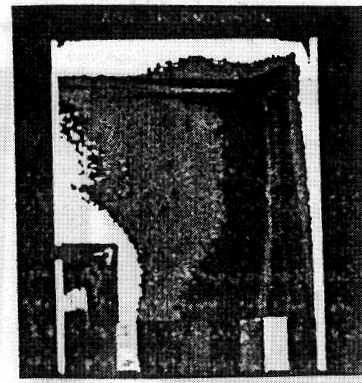
A1



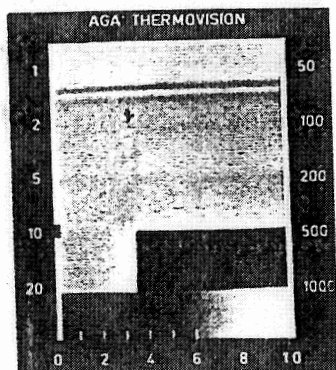
A2 $\Delta t = 6.5^\circ\text{C}$



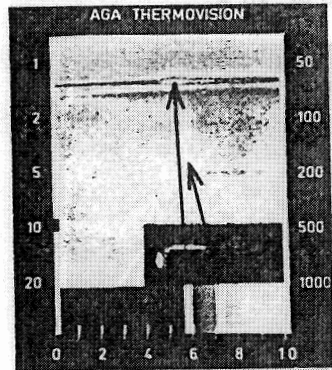
A3 $\Delta t = 5.8^\circ\text{C}$



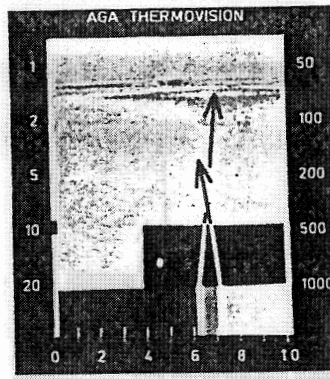
A4



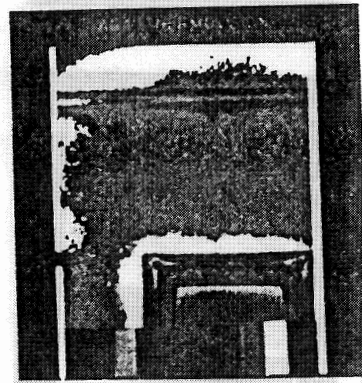
B1



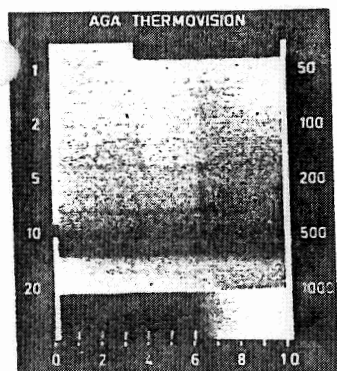
B2 $\Delta t = 2.2^\circ\text{C}$



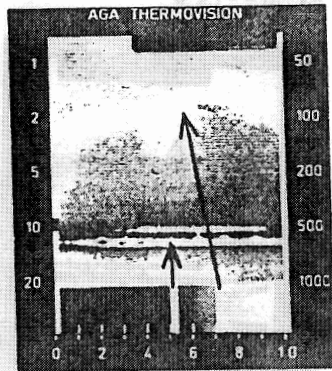
B3 $\Delta t = 1.5^\circ\text{C}$



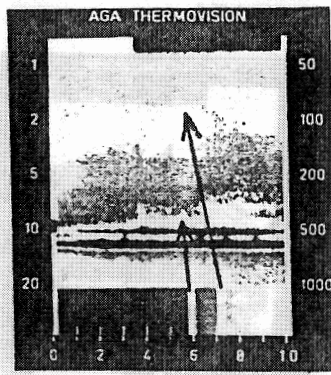
B4



C1



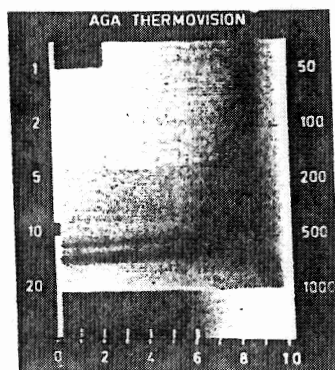
C2 $\Delta t = 3.5^\circ\text{C}$



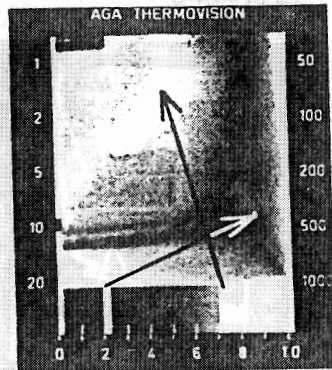
C3 $\Delta t = 2.1^\circ\text{C}$



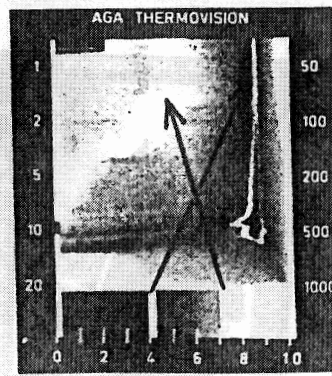
C4



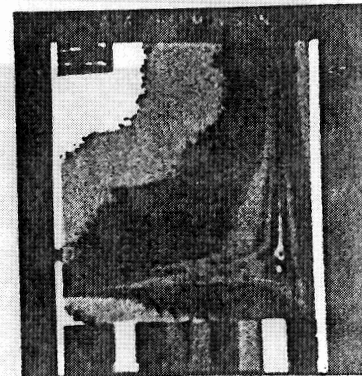
D1



D2 $\Delta t = 9.7^\circ\text{C}$



D3 $\Delta t = 5.7^\circ\text{C}$



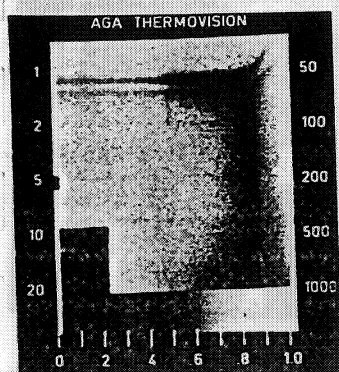
D4

Lättbetongvägg / Lightweight concrete wall

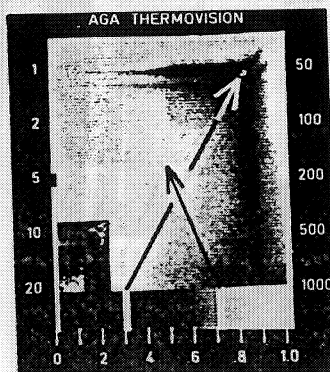
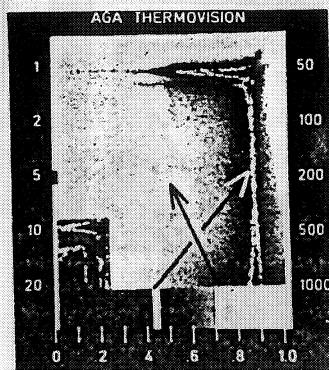
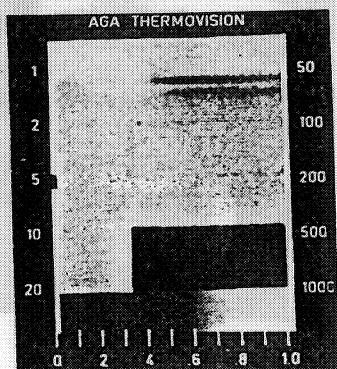
Konstruktion med inbyggda fel / Design with deliberate faults

Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 11^\circ\text{C}$

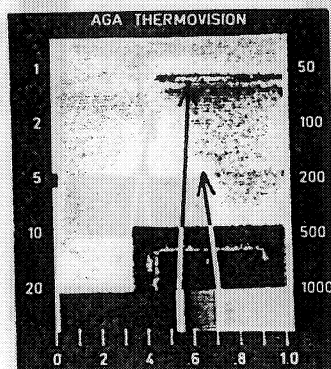
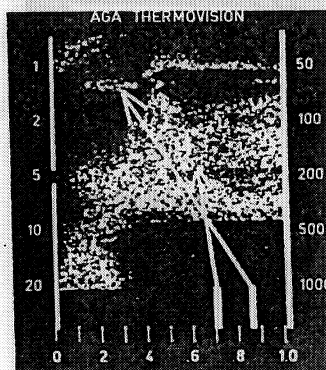
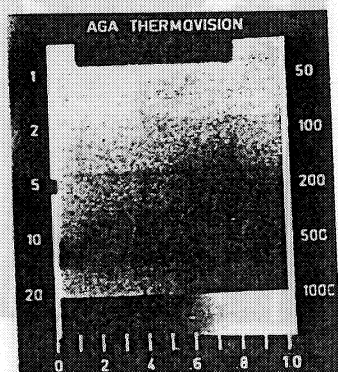
Tryckskillnad (inne – ute) /
Difference in pressure (indoors – outdoors): $p_i - p_u = 0 \text{ N/m}^2$



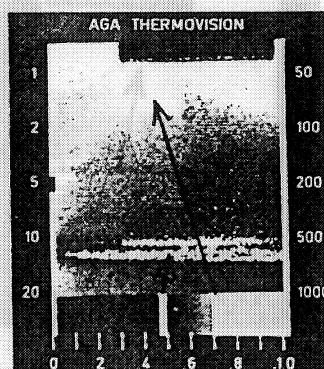
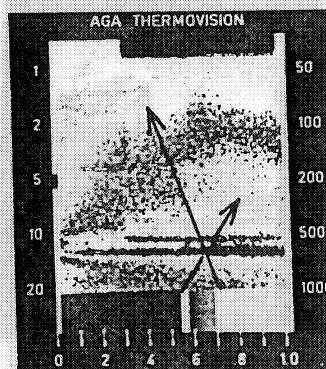
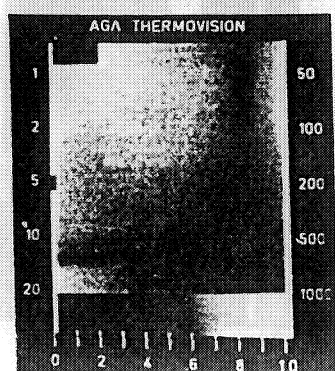
A1

A2 $\Delta t = 3.3^\circ\text{C}$ A3 $\Delta t = 2.1^\circ\text{C}$ 

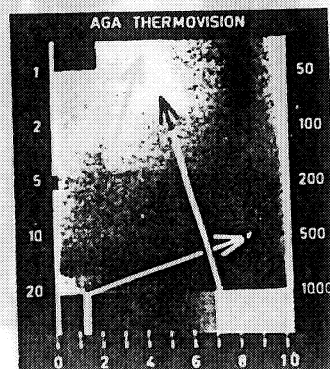
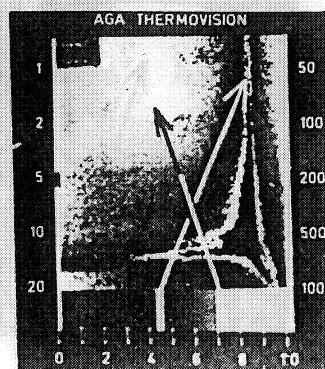
B1

B2 $\Delta t = 1.3^\circ\text{C}$ B3 $\Delta t = -1.2^\circ\text{C}$ 

C1

C2 $\Delta t = 1.8^\circ\text{C}$ C3 $\Delta t = 1.1^\circ\text{C}$ 

D1

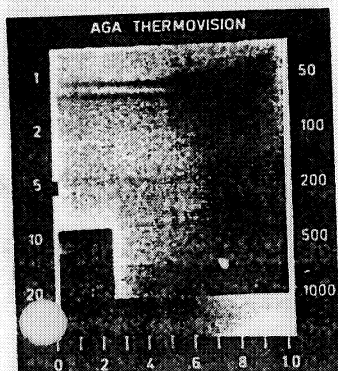
D2 $\Delta t = 4.8^\circ\text{C}$ D3 $\Delta t = 2.1^\circ\text{C}$

Lättbetongvägg / Lightweight concrete wall

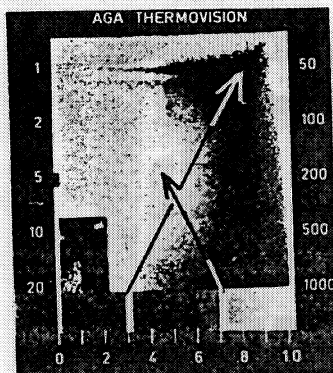
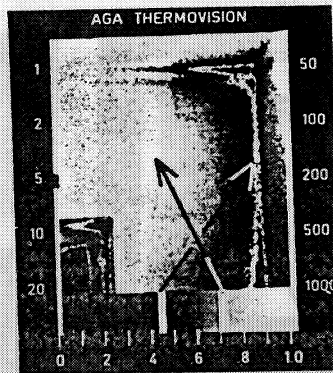
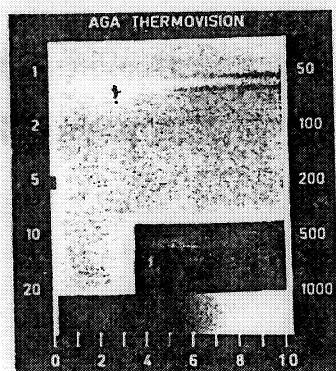
Konstruktion med inbyggda fel / Design with deliberate faults

Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 11^\circ\text{C}$

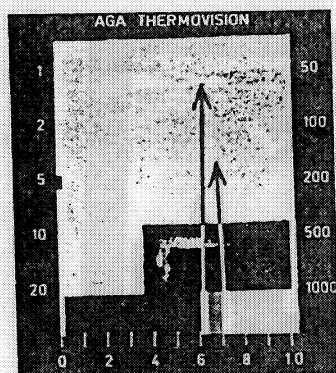
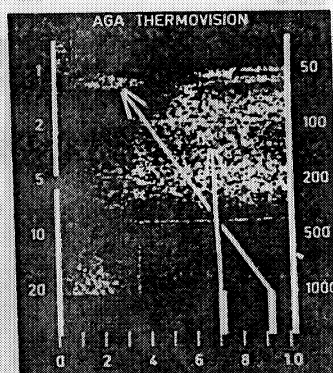
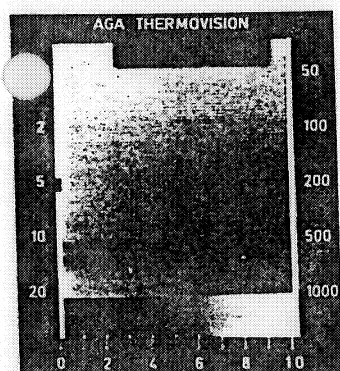
Tryckskillnad (inne – ute) /
Difference in pressure (indoors – outdoors): $p_i - p_u = +50 \text{ N/m}^2$



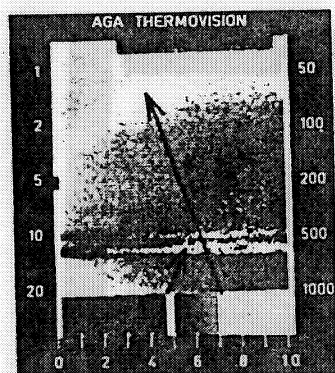
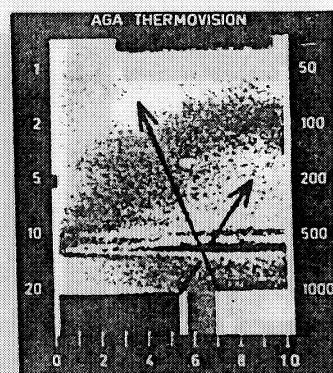
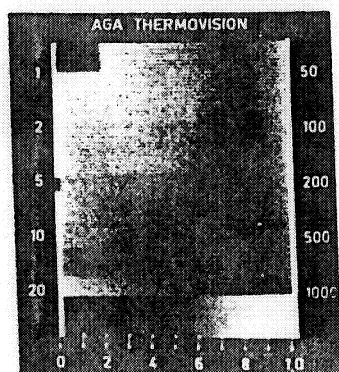
A1

A2 $\Delta t = 3.3^\circ\text{C}$ A3 $\Delta t = 2.1^\circ\text{C}$ 

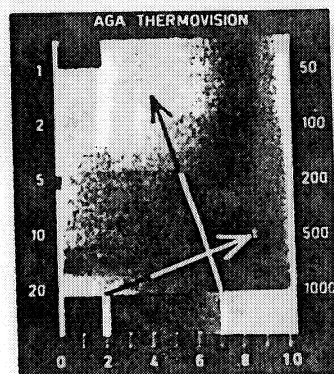
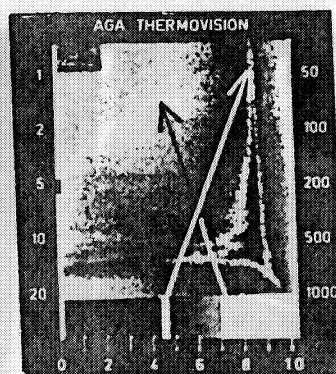
B1

B2 $\Delta t = 0.7^\circ\text{C}$ B3 $\Delta t = -1.6^\circ\text{C}$ 

C1

C2 $\Delta t = 1.7^\circ\text{C}$ C3 $\Delta t = 1.2^\circ\text{C}$ 

D1

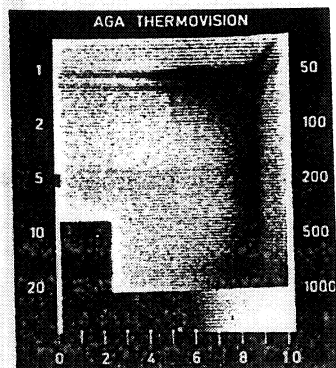
D2 $\Delta t = 4.2^\circ\text{C}$ D3 $\Delta t = 2.1^\circ\text{C}$

Temperaturskillnad (inne – ute) /

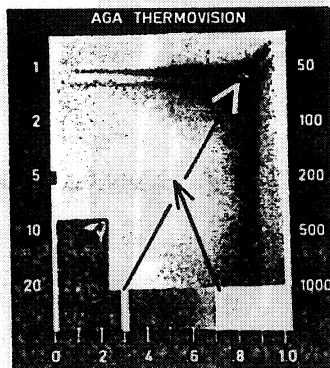
Difference in temperature (indoors – outdoors): $t_i - t_u = 11^\circ\text{C}$

Tryckskillnad (inne – ute) /

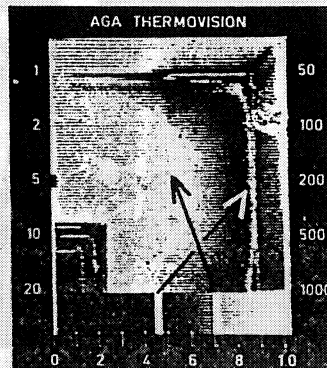
Difference in pressure (indoors – outdoors): $p_i - p_u = -50\text{ N/m}^2$



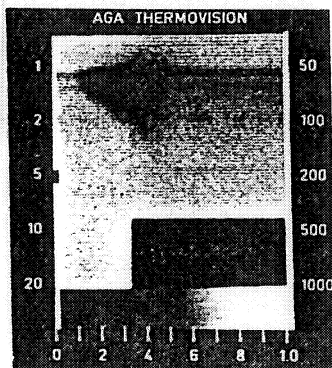
A1



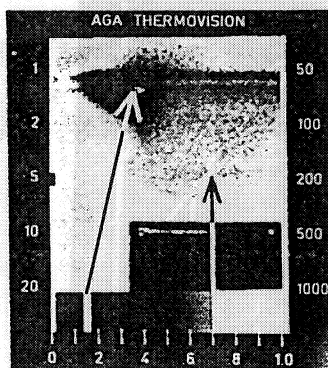
A2 $\Delta t = 3.3^\circ\text{C}$



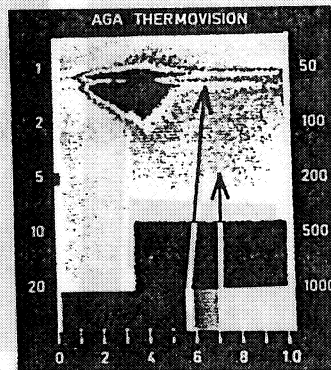
A3 $\Delta t = 1.9^\circ\text{C}$



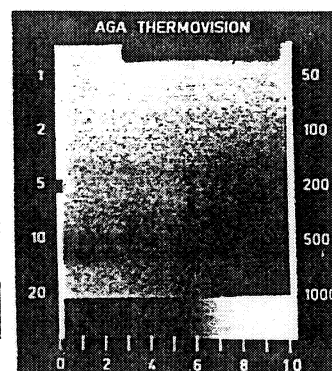
B1



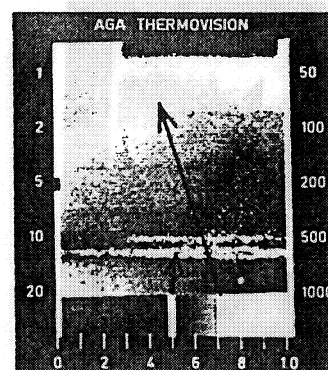
B2 $\Delta t = 4.6^\circ\text{C}$



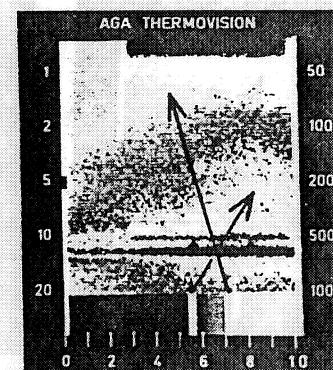
B3 $\Delta t = 1.1^\circ\text{C}$



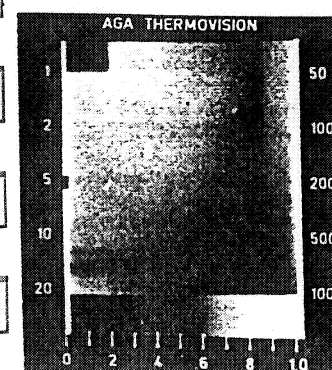
C1



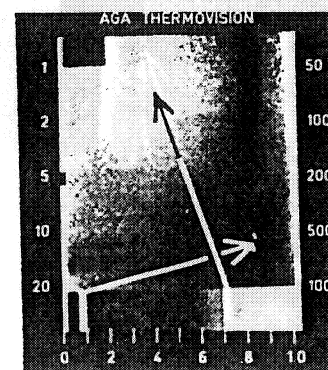
C2 $\Delta t = 1.7^\circ\text{C}$



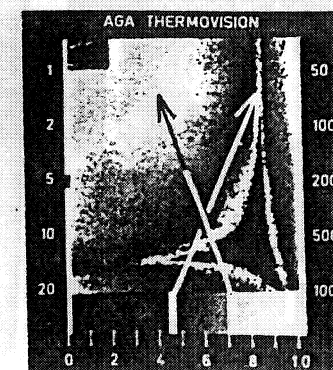
C3 $\Delta t = 1.1^\circ\text{C}$



D1



D2 $\Delta t = 5.3^\circ\text{C}$

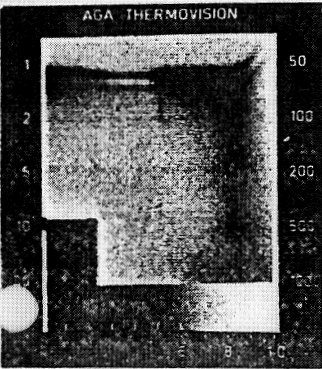


D3 $\Delta t = 1.9^\circ\text{C}$

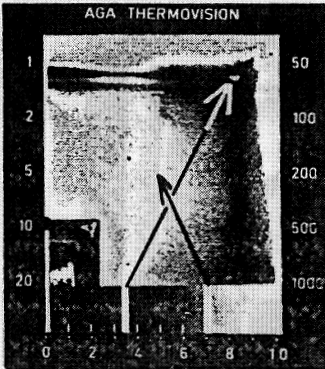
Lättbetongvägg / Lightweight concrete wall
Konstruktion med inbyggda fel / Design with deliberate faults

Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 26^{\circ}\text{C}$

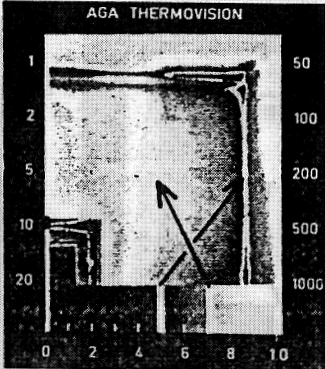
Tryckskillnad (inne – ute) /
Difference in pressure (indoors – outdoors): $p_i - p_u = 0\text{ N/m}^2$



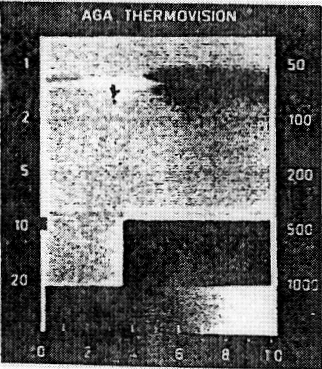
A1



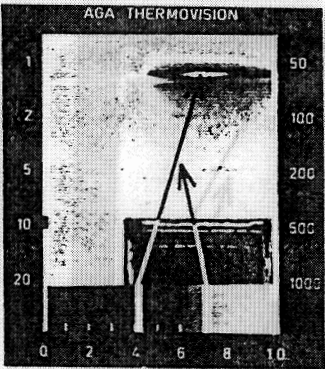
A2 $\Delta t = 6.6^{\circ}\text{C}$



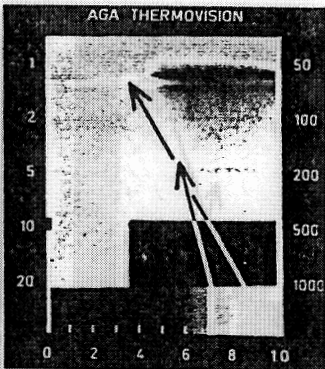
A3 $\Delta t = 3.8^{\circ}\text{C}$



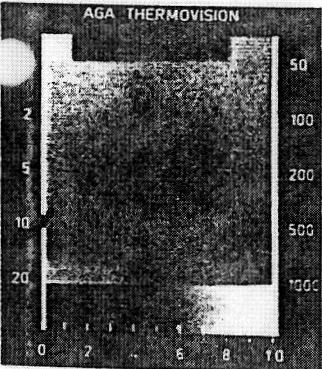
B1



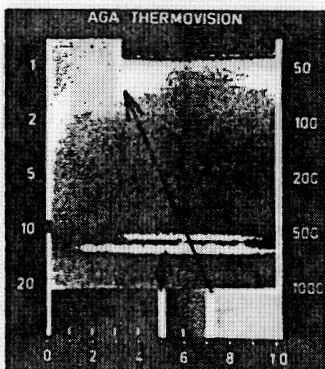
B2 $\Delta t = 5.2^{\circ}\text{C}$



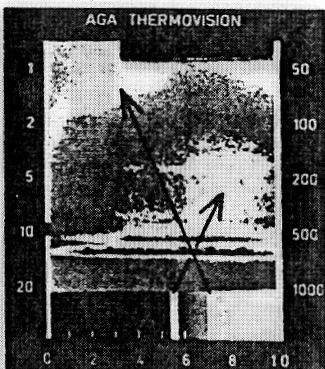
B3 $\Delta t = -2.2^{\circ}\text{C}$



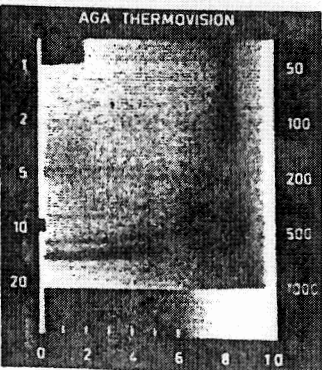
C1



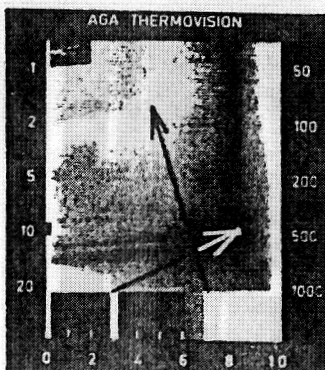
C2 $\Delta t = 3.4^{\circ}\text{C}$



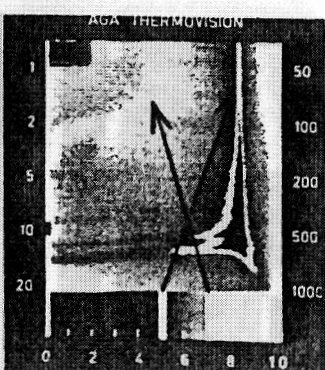
C3 $\Delta t = 2.6^{\circ}\text{C}$



D1



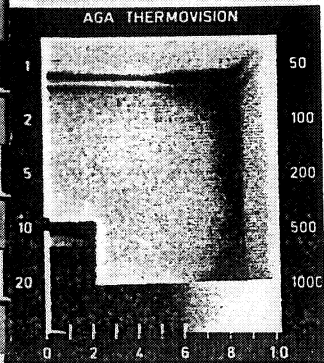
D2 $\Delta t = 7.5^{\circ}\text{C}$



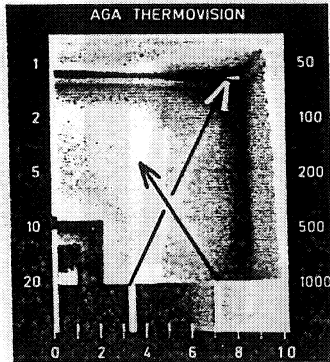
D3 $\Delta t = 3.5^{\circ}\text{C}$

Temperaturskillnad (inne – ute) /
 Difference in temperature (indoors – outdoors): $t_i - t_u = 26^\circ\text{C}$

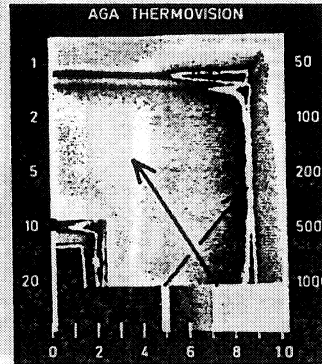
Tryckskillnad (inne – ute) /
 Difference in pressure (indoors – outdoors): $p_i - p_u = +50\text{ N/m}^2$



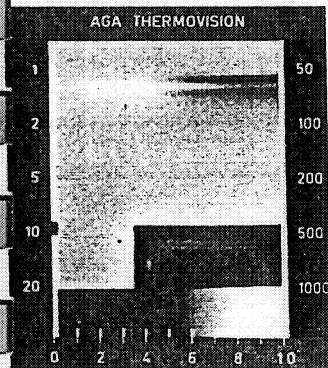
A1



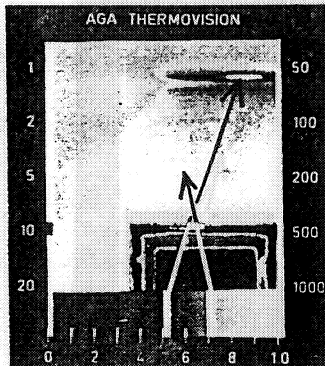
A2 $\Delta t = 6.8^\circ\text{C}$



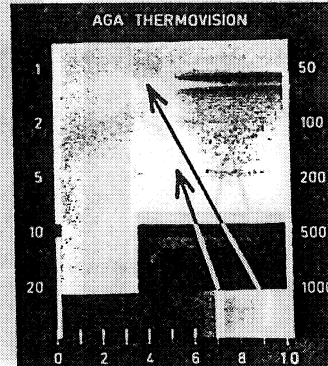
A3 $\Delta t = 3.8^\circ\text{C}$



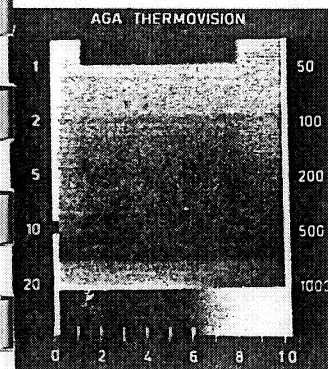
B1



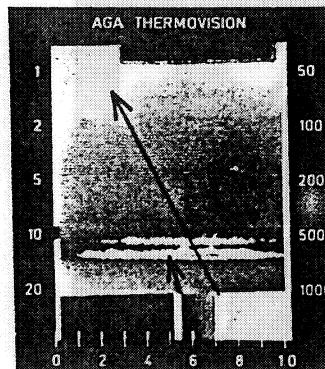
B2 $\Delta t = 3.3^\circ\text{C}$



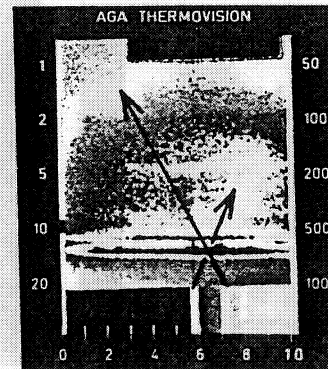
B3 $\Delta t = -2.5^\circ\text{C}$



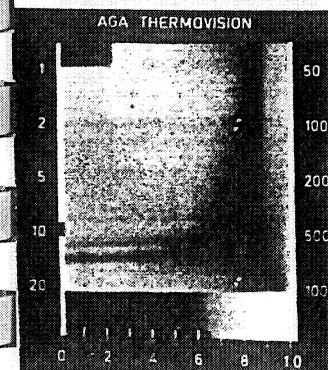
C1



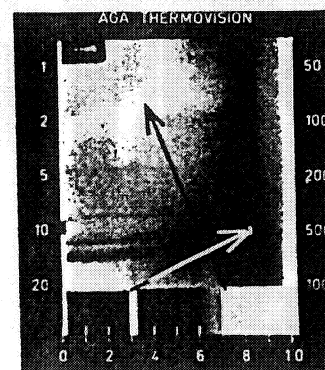
C2 $\Delta t = 3.0^\circ\text{C}$



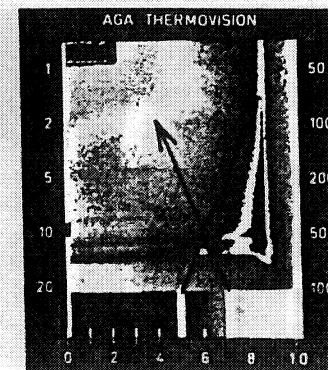
C3 $\Delta t = 2.2^\circ\text{C}$



D1



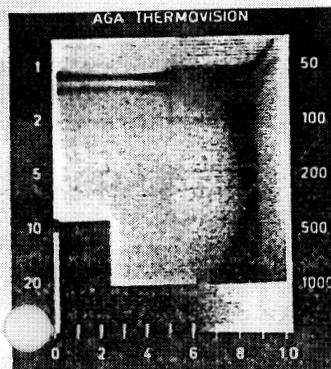
D2 $\Delta t = 7.3^\circ\text{C}$



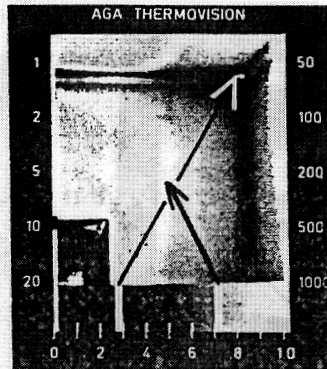
D3 $\Delta t = 3.7^\circ\text{C}$

Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 26^\circ\text{C}$

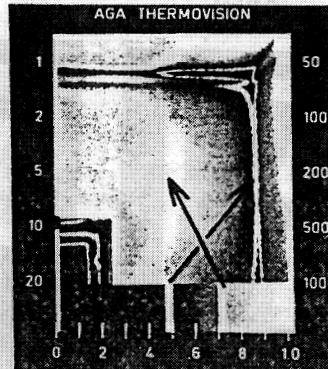
Tryckskillnad (inne – ute) /
Difference in pressure (indoors – outdoors): $p_i - p_u = -50\text{ N/m}^2$



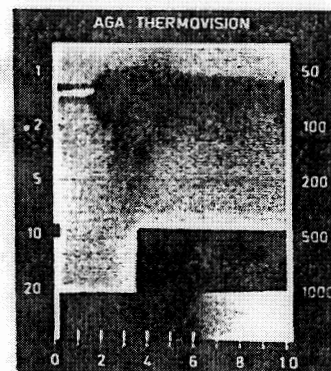
A1



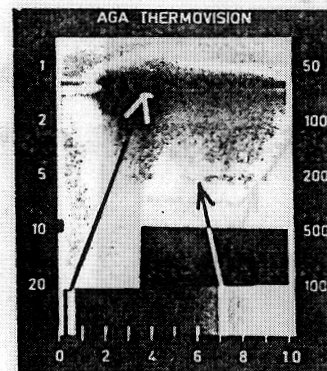
A2 $\Delta t = 7.8^\circ\text{C}$



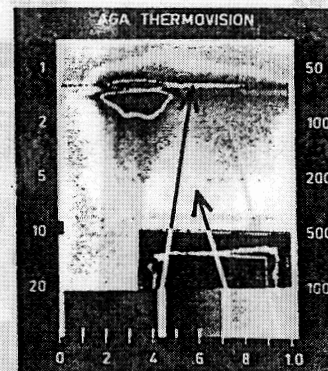
A3 $\Delta t = 3.9^\circ\text{C}$



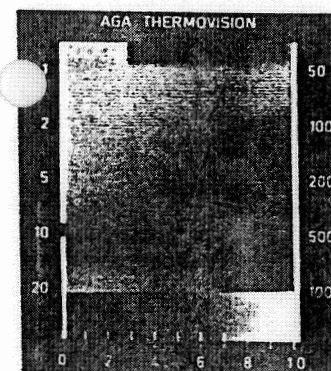
B1



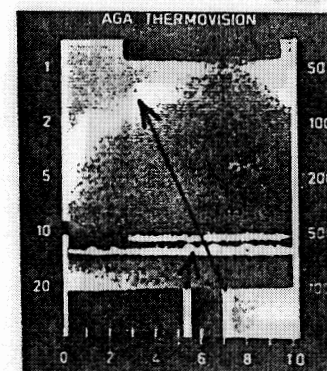
B2 $\Delta t = 12.8^\circ\text{C}$



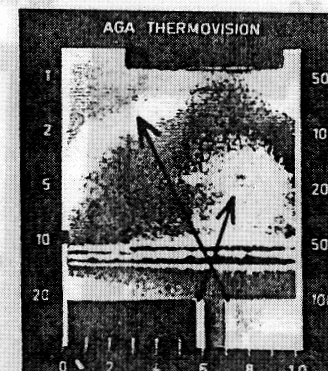
B3 $\Delta t = 5.0^\circ\text{C}$



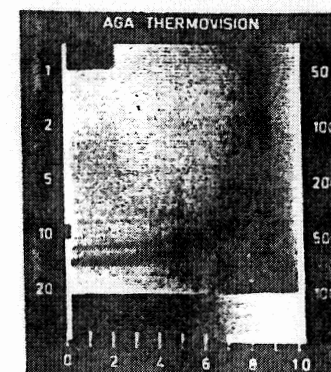
C1



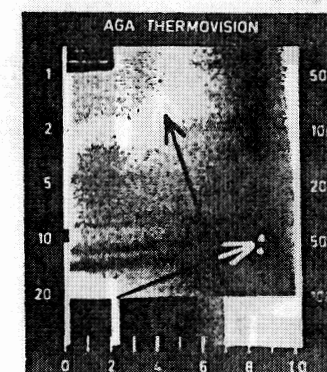
C2 $\Delta t = 3.0^\circ\text{C}$



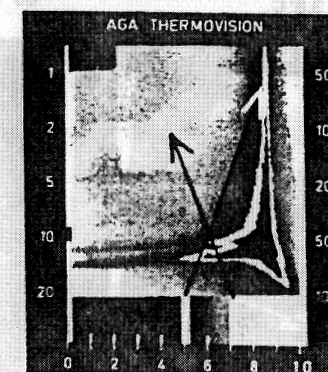
C3 $\Delta t = 2.0^\circ\text{C}$



D1



D2 $\Delta t = 9.2^\circ\text{C}$

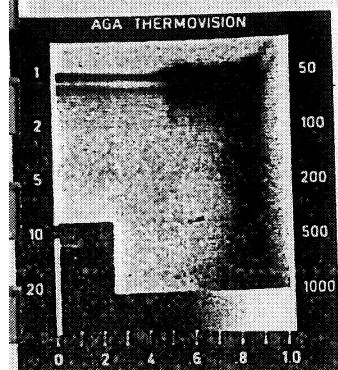


D3 $\Delta t = 3.5^\circ\text{C}$

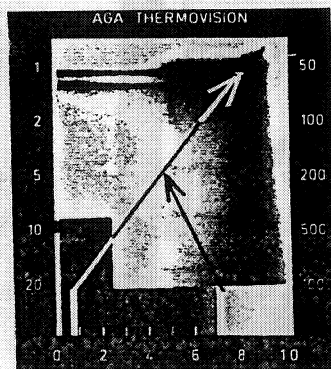
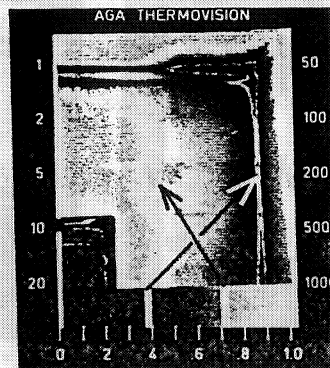
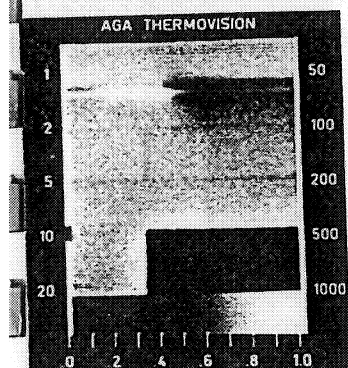
Lättbetongvägg / Lightweight concrete wall
 Konstruktion med inbyggda fel / Design with deliberate faults

Temperaturskillnad (inne – ute) /
 Difference in temperature (indoors – outdoors): $t_i - t_u = 41^\circ\text{C}$

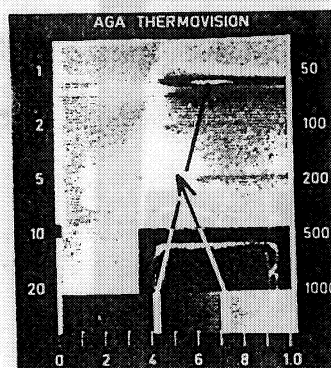
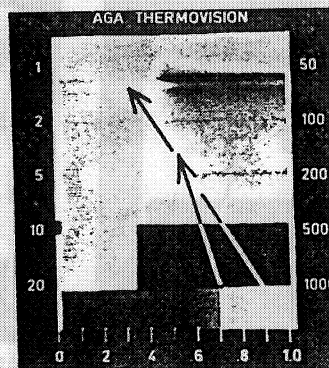
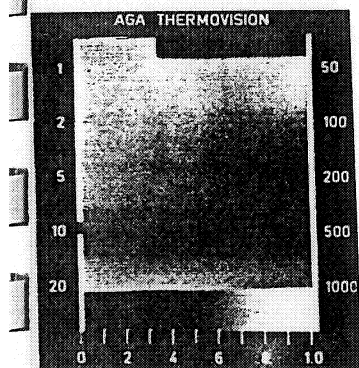
Tryckskillnad (inne – ute) /
 Difference in pressure (indoors – outdoors): $p_i - p_u = 0 \text{ N/m}^2$



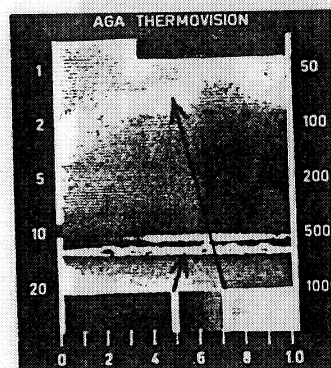
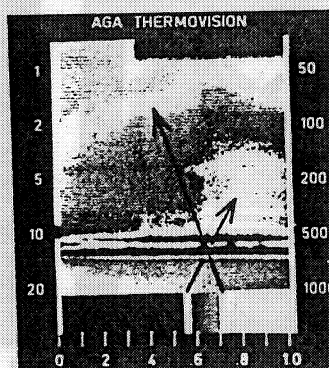
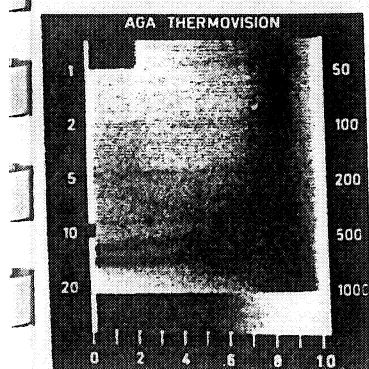
A1

A2 $\Delta t = 12.7^\circ\text{C}$ A3 $\Delta t = 6.1^\circ\text{C}$ 

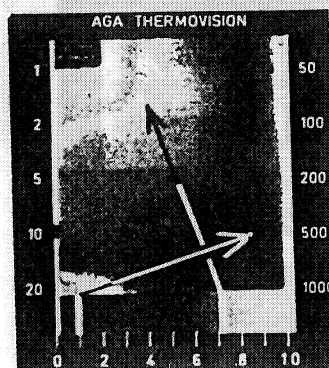
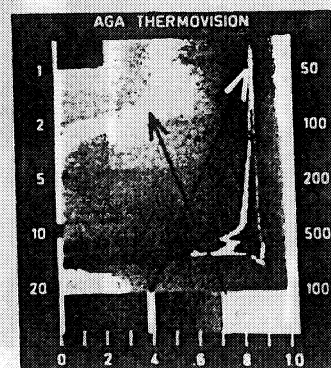
B1

B2 $\Delta t = 5.3^\circ\text{C}$ B3 $\Delta t = -2.8^\circ\text{C}$ 

C1

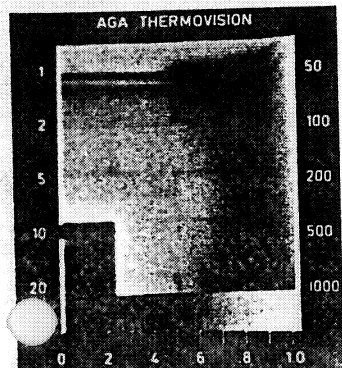
C2 $\Delta t = 3.8^\circ\text{C}$ C3 $\Delta t = 2.5^\circ\text{C}$ 

D1

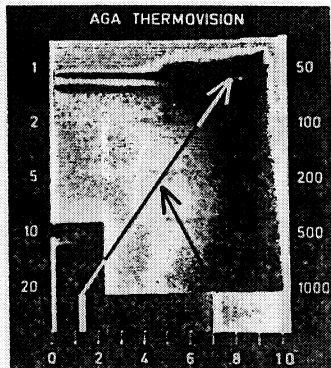
D2 $\Delta t = 12.6^\circ\text{C}$ D3 $\Delta t = 6.0^\circ\text{C}$

Temperaturskillnad (inne – ute) /
 Difference in temperature (indoors – outdoors): $t_i - t_u = 41^\circ\text{C}$

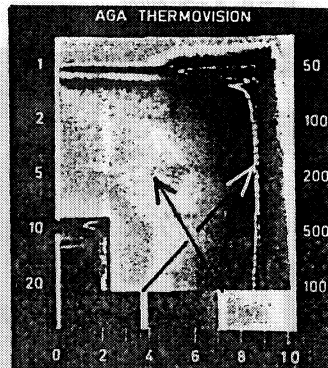
Tryckskillnad (inne – ute) /
 Difference in pressure (indoors – outdoors): $p_i - p_u = +50 \text{ N/m}^2$



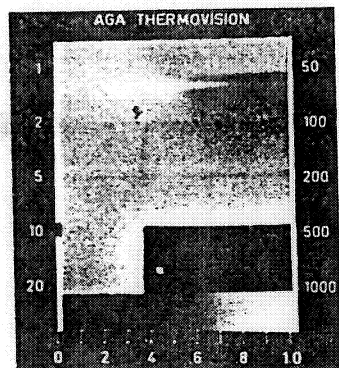
A1



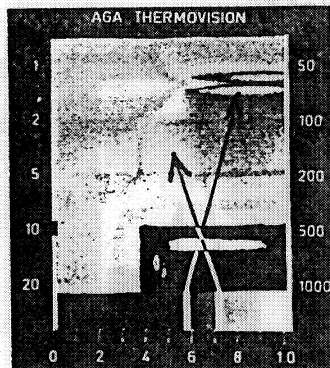
A2 $\Delta t = 11.8^\circ\text{C}$



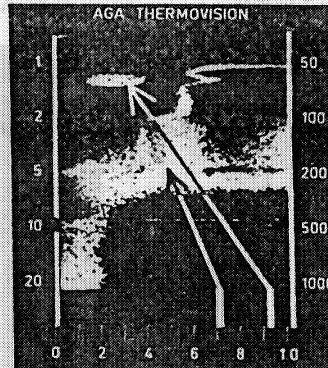
A3 $\Delta t = 6.1^\circ\text{C}$



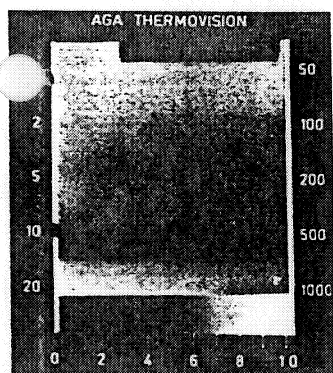
B1



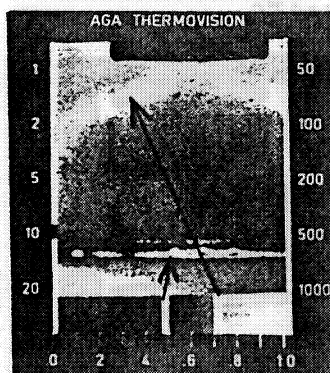
B2 $\Delta t = 2.3^\circ\text{C}$



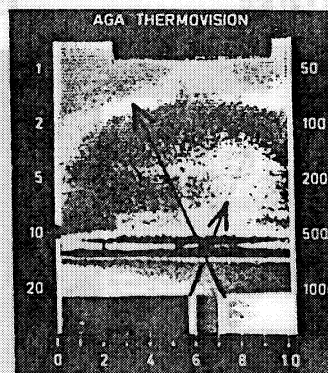
B3 $\Delta t = -3.3^\circ\text{C}$



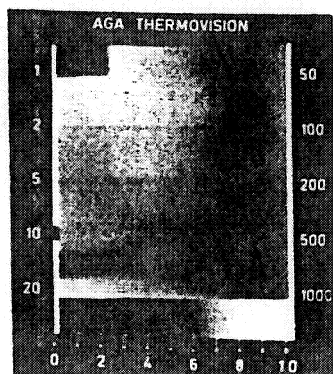
C1



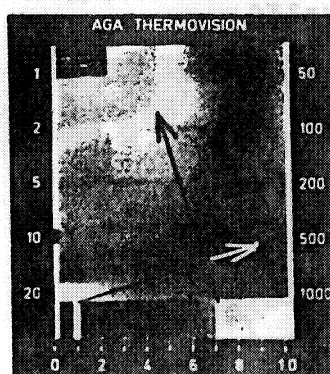
C2 $\Delta t = 3.8^\circ\text{C}$



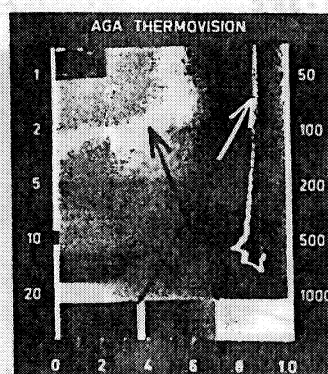
C3 $\Delta t = 2.2^\circ\text{C}$



D1



D2 $\Delta t = 12.6^\circ\text{C}$



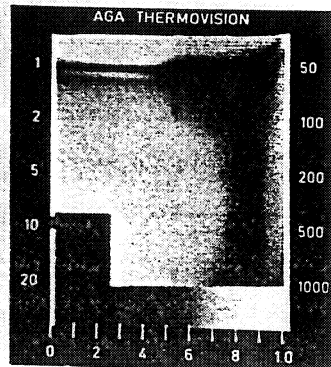
D3 $\Delta t = 6.2^\circ\text{C}$

Temperaturskillnad (inne – ute) /

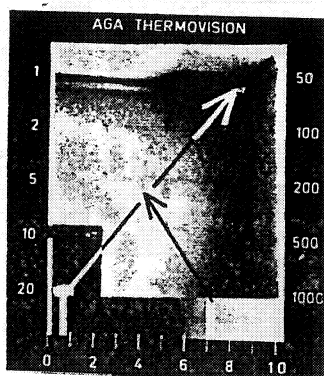
Difference in temperature (indoors – outdoors): $t_i - t_u = 41^\circ\text{C}$

Tryckskillnad (inne – ute) /

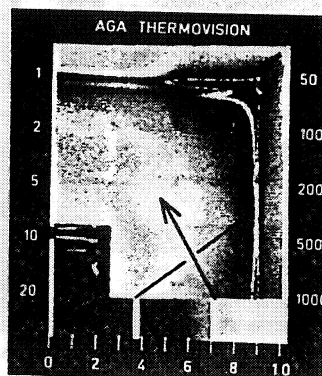
Difference in pressure (indoors – outdoors): $p_i - p_u = -50\text{ N/m}^2$



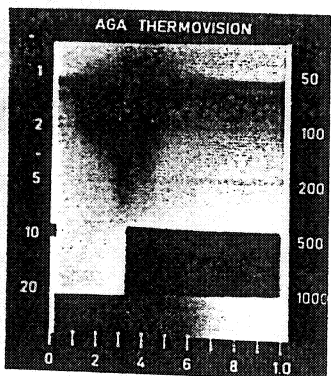
A1



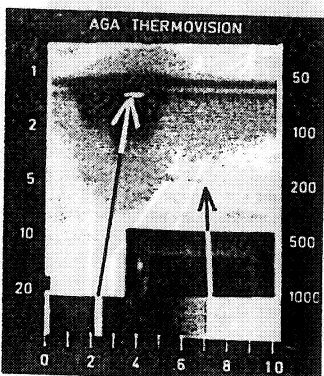
A2 $\Delta t = 12.9^\circ\text{C}$



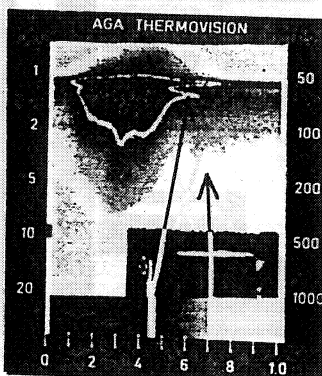
A3 $\Delta t = 6.3^\circ\text{C}$



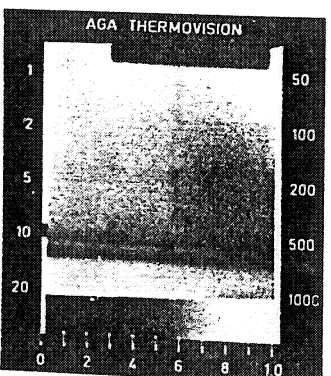
B1



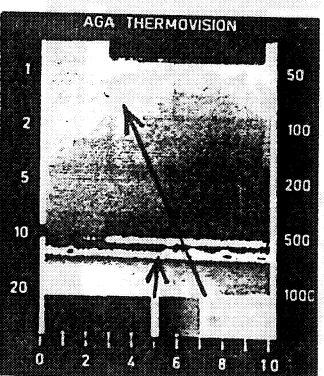
B2 $\Delta t = 21.5^\circ\text{C}$



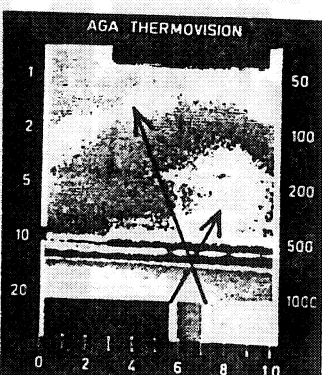
B3 $\Delta t = 4.7^\circ\text{C}$



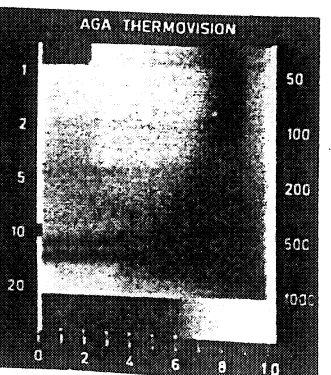
C1



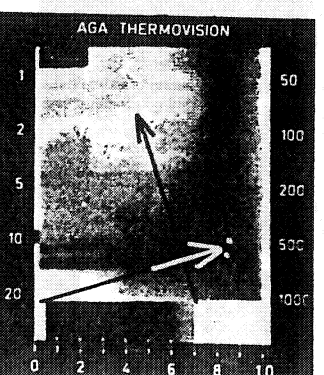
C2 $\Delta t = 3.6^\circ\text{C}$



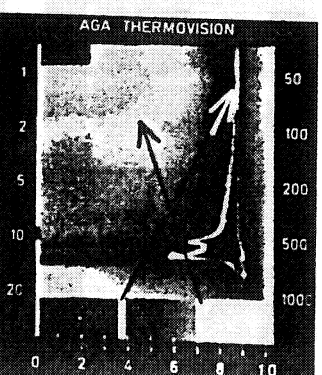
C3 $\Delta t = 2.3^\circ\text{C}$



D1



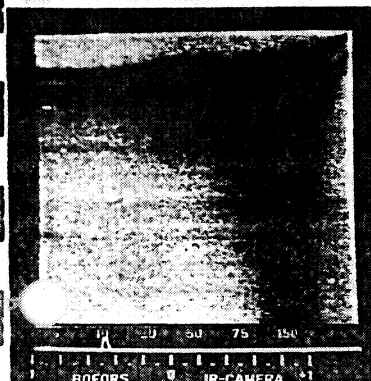
D2 $\Delta t = 13.9^\circ\text{C}$



D3 $\Delta t = 6.2^\circ\text{C}$

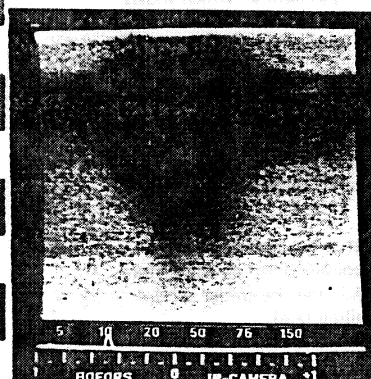
Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 41^\circ\text{C}$

Tryckskillnad (inne – ute) /
Difference in pressure (indoors – outdoors): $p_i - p_u = -50 \text{ N/m}^2$



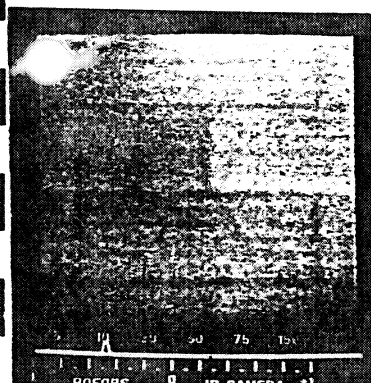
A1 Gråtonsbild $12.5 \times 12.5^\circ$.
Nedkylt ytparti vid takhorn (isoleringsfel, se FIG. 25 fel nr 5).
Det visade ytpartiet motsvarar den högra halvan av den förstörade gråtonsbilden.

A1 Monochrome image $12.5 \times 12.5^\circ$.
Section of surface at corner of ceiling colder (fault in insulation, see FIG. 25, fault No 5). The section of surface shown is the same as the right-hand half of the expanded monochrome image.



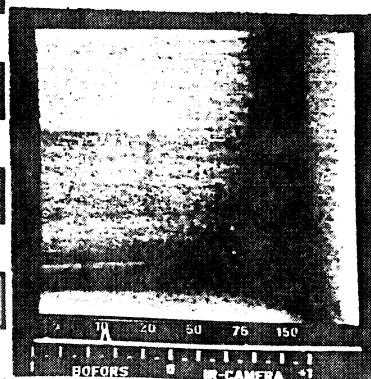
B1 Gråtonsbild $12.5 \times 12.5^\circ$.
Nedkylt ytparti p g a luftläckage (se FIG. 25 fel nr 6).
Det visade ytpartiet motsvarar den vänstra halvan av den förstörade gråtonsbilden.

B1 Monochrome image $12.5 \times 12.5^\circ$.
Section of surface colder due to leakage of air (see FIG. 25, fault No 6). The section of surface shown is the same as the left-hand half of the expanded monochrome image.



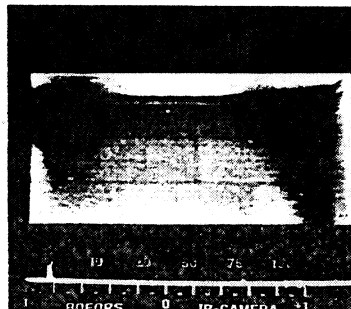
C1 Gråtonsbild $12.5 \times 12.5^\circ$. En lättbetongstav i mitten av bilden har en mörkare gråton (kallare). Detta beror på att en del av betongstaven är borttagen, se FIG. 25 fel nr 1. Även limfogarna mellan betongstavarna framträder som mörkare ränder (kallare partier). Det visade ytpartiet motsvarar den mellersta delen av den förstörade gråtonsbilden.

C1 Monochrome image $12.5 \times 12.5^\circ$. A lightweight concrete plank in the middle of the picture is a darker shade of grey (colder). This is due to part of the plank having been removed, see FIG. 25, fault No 1. The glued joints between the planks also appear as darker strips (colder portions). The section of surface shown is the same as the centre portion of the expanded monochrome image.



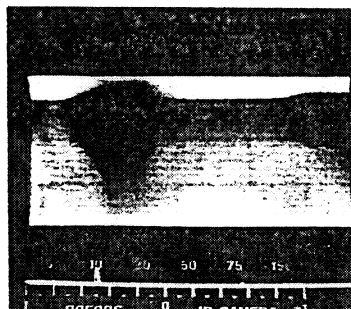
D1 Gråtonsbild $12.5 \times 12.5^\circ$.
Nedkylt ytparti vid golvhorn (del av hörnsten borttagen, se FIG. 25 fel nr 7).
Det visade ytpartiet motsvarar den högra halvan av den förstörade gråtonsbilden.

D1 Monochrome image $12.5 \times 12.5^\circ$.
Section of surface at corner of floor colder (part of corner block removed, see FIG. 25, fault No 7). The section of surface shown is the same as the right-hand half of the expanded monochrome image.



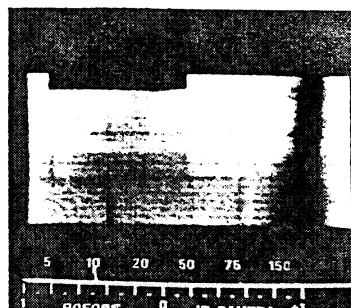
A1 Gråtonsbild förstörad i horisontell led. $25 \times 12.5^\circ$.

A1 Monochrome image expanded in the horizontal direction. $25 \times 12.5^\circ$.



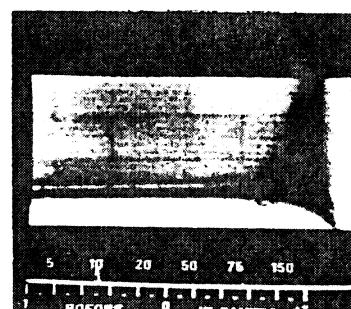
B1 Gråtonsbild förstörad i horisontell led. $25 \times 12.5^\circ$.

B1 Monochrome image expanded in the horizontal direction. $25 \times 12.5^\circ$.



C1 Gråtonsbild förstörad i horisontell led. $25 \times 12.5^\circ$.

C1 Monochrome image expanded in the horizontal direction. $25 \times 12.5^\circ$.



D1 Gråtonsbild förstörad i horisontell led. $25 \times 12.5^\circ$.

D1 Monochrome image expanded in the horizontal direction. $25 \times 12.5^\circ$.

Exempel på termogram tagna med BOFORS IR-kamera (jämför med BIL. 54 där termogram från motsvarande ytpartier tagna med AGAs IR-kamera visas).

Boforskameran är utrustad med en funktion som möjliggör direkt byte mellan två bildvinklar, $12 \times 12.5^\circ$ och $25 \times 12.5^\circ$. Det senare fallet möjliggör exponering av en större yta i horisontell led (se de mindre termogrammen till vänster).

Funktionerna hos de båda kameratyperna AGA och BOFORS är i princip lika. Konstruktionsmässigt föreligger mindre olikheter. Dessa olikheter påverkar emellertid inte nämnvärt termogrammens utseende.

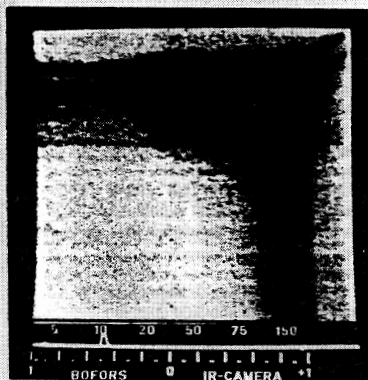
Examples of thermograms taken with the BOFORS IR-camera (compare with Appendix 54 which shows thermograms of the same surfaces taken with the AGA IR-camera).

The BOFORS camera is equipped with a function which makes possible a direct change between two view angles, $12.5 \times 12.5^\circ$ and $25 \times 12.5^\circ$. The latter enables exposures to be made of surfaces with a larger horizontal dimension (see the smaller thermogram to the left).

The functions of the AGA and BOFORS cameras are in principle the same. There are some minor differences in the design, but these do not appreciably affect the appearance of the thermogram.

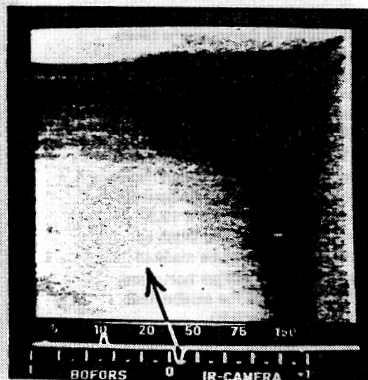
Temperaturskillnad (inne – ute) /
Difference in temperature (indoors – outdoors): $t_i - t_u = 41^\circ\text{C}$

Tryckskillnad (inne – ute) /
Difference in preasure (indoors – outdoors): $p_i - p_u = -50 \text{ N/m}^2$

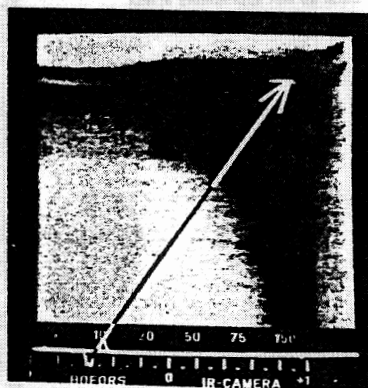


A1 Gråtonsbild
Nedkylt ytparti vid takvinkel. Nedkylningen är försakad av isoleringsfel (se FIG. 25 fel nr 5).

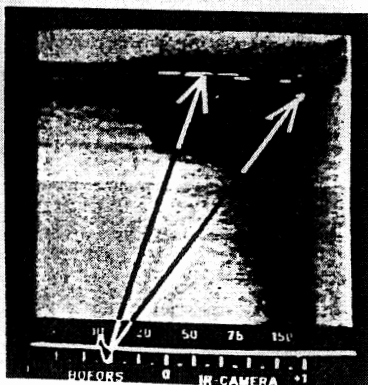
A1 Monochrome image
Colder surface at the junction of wall and ceiling. The reason why this portion of the surface is colder is that there is a fault in insulation (see FIG. 25, fault No 5).



A2 $\Delta D = 0$
 $t_1 = 17.5^\circ\text{C}$



A3 $\Delta D = -0.66$
 $\Delta t = 13.2^\circ\text{C}$



A4 $\Delta D = -0.50$
 $\Delta t = 9.3^\circ\text{C}$

Exempel på bestämning av yttemperaturfördelning ur termogram tagna med BOFORS IR-kamera (jämför BIL. 54 där termogram från motsvarande ytpartier tagna med AGAs IR-kamera visas).

- t_1 med termoelement uppmätt yttemperatur hos felfritt väggparti
- ΔD isotermmarkeringens läge på den nedersta horisontella mätskalan. Isotermen kan inställas från +1 till -1. Dess läge kan avläsas mera noggrant på en graderad inställningsratt
- Δt uppmätt temperaturskillnad mellan felfritt väggparti och den kallaste ytpunkten vid takhörnet (A3) respektive nedkylt ytparti vid takvinkel (A4)

Example of the determination of the distribution of surface temperature on the basis of thermograms taken with the BOFORS IR-camera (compare with Appendix 54 which shows thermograms of the same surfaces taken with the AGA IR-camera).

- t_1 surface temperature measured with a thermocouple on a portion of the wall without a fault
- ΔD the position of the isotherm marking on the bottom horizontal graduation scale. The isotherm can be set from +1 to -1. Its position can be read more accurately on a graduated tuning wheel.
- Δt measured temperature difference between portion of wall without a fault and the coldest point on the surface at the corner of the ceiling (A3) and the colder surface at the junction of wall and ceiling (A4).