LUND UNIVERSITY

Research and development in building physics during the last 25 years : symposium to celebrate Lars Erik Nevander's 70 years birthday : Dept. of Building Physics, Lund University, Sweden, Friday 13 September 1991

Nevander, Lars-Erik; Elmroth, Arne

1992

Link to publication

Citation for published version (APA):
Nevander, L.-E., & Elmroth, A. (Eds.) (1992). *Research and development in building physics during the last 25 years : symposium to celebrate Lars Erik Nevander's 70 years birthday : Dept. of Building Physics, Lund University, Sweden, Friday 13 September 1991*. (BFR Document 1992:15). Swedish Council for Building Research.

Total number of authors:
2

General rights
Unless other specific re-use rights are stated the following general rights apply:
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.
• Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
• You may not further distribute the material or use it for any profit-making activity or commercial gain
• You may freely distribute the URL identifying the publication in the public portal

Read more about Creative commons licenses: https://creativecommons.org/licenses/

Take down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

LUND UNIVERSITY

PO Box 117
221 00 Lund
+46 46-222 00 00

Research and Development in Building Physics during the last 25 years

SYMPOSIUM TO CELEBRATE PROFESSOR LARS ERIK NEVANDER´S 70 YEARS BIRTHDAY

BYGGFORSKNINGSRÅDET

D15:1992

Symposium to celebrate professor Lars Erik Nevander's 70 years birthday

Research and Development in Building Physics during the last 25 years

Dept. of Building Physics, Lund University, Sweden

Friday 13 September 1991

Authors:
A. Elmroth
B. Petterson
G. Anderlind
R.P. Tye
C. Bankvall
A. Nielsen
H. Hens
M. Bomberg
V. Korsgaard
P. I. Sandberg
L.-E. Harderup
E. Tammes
G. Essunger
T. Degerman
M. Andersson
G. Dahl
S. Nilsson
S. Karlsson

This document refers to research grant No 910546-2 from the Swedish Council for Building Research to the Dept. of Building Physics, Lund University, Sweden.

Cover: Ulf Hed

Copyright: Swedish Council for Building Research,
Stockholm 1992

Printed on low-pollution, unbleached paper.

Document D15:1992

ISBN 91-540-5497-4
Swedish Council for Building Research, Stockholm, Sweden

Ljunglöfs Offset AB, Stockholm 1992

CONTENTS

Research and Development in Building Physics during the last 25 Years

Foreword

This book is dedicated to Lars Erik Nevander, who turned 70 in the autumn of 1991. An international symposium was held in Lund in September of 1991 to which participants were specially invited who had worked with Lars Erik Nevander in one connection or another during the time of his professorship at Lund University. Invited papers presented by some 20 of the participants illuminated important developments in building physics during the past quarter-century. These papers are published here in their original form.

The papers provide an interesting overview of advances in building physics both in Sweden and internationally. They deal with such differing topics as heat insulation, moisture transport, measuring and sampling techniques, wall construction, roofing, and both national and international building standards. From the papers it becomes clear that marked progress has been made in building physics in recent years. One can virtually speak of a revolution in the technical possibilities and solutions which have been discovered. Present-day knowledge allow materials to be utilized in a highly effective way. We can build more energy-efficient and moisture-free houses with better comfort and convenience than ever before. The dissemination of knowledge of such matters, however, has not always been adequate. This has led to such failures as the building of houses later diagnosed as being afflicted with the "Sick Building Syndrome" (SBS). Failures of this sort are also due to the fact that, as increasing knowledge enables techniques to be refined for making optimal use of the characteristics of various materials, the risk of mistakes increases as well. Even slight mistakes may have far-reaching consequences. Insights based both on theoretical considerations and on results of laboratory experiments need to be presented in even more readily accessible form than heretofore. Lars Erik Nevander has been a pioneer in finding sound practical applications based on a thorough understanding of theoretical principles. Those of us who work with building physics and its applications have a deep responsibility for continuing work in this tradition.

Lund, July 1992

Arne Elmroth

Arne Elmroth
Dept. of Building Physics, Lund University
Sweden

THE AIM OF THE WORK AND THE RESEARCH PROJECTS AT THE DEPARTMENT OF BUILDING PHYSICS

The subject comprises fundamental and applied building physics, with particular emphasis on heat transfer, moisture transfer and air flow in buildings and parts of buildings, as well as their construction and form, in particular from the point of view of the requirements of building physics.

The overall aim of the basic training is to provide the knowledge necessary to be able to design and build houses which are healthy, comfortable and are energy efficient. This is achieved by giving basic and advanced instruction in building physics, and applying this knowledge, in particular concerning building materials and installation techniques, to the design of various sections of a building. The instruction is given in the form of compulsory and as advanced courses.

At the department research projects are also being undertaken. The overall aim here is to arrive at an understanding of and to use basic building physics in the construction of theoretical models with which to solve practical problems. Great importance is attached to the ability to structure a given problem or question, from a theoretical as well as from a practical perspective. The research student is to learn scientific methodology and be able to apply the results in a critical way. Considerable importance is given to the ability to present and provide information on the results of the research programme in hand.

The department has a long tradition in research concerning problems of heat and moisture in buildings. The results of this research have attracted attention, both within Sweden and internationally. This research has had the effect, among other things, that the technology now used has made possible the production in Sweden of the most energy-efficient and at the same time the most comfortable houses in the world. This development over the past 15 - 20 years can be seen almost as a revolution, which has, unfortunately also resulted in several consequential problems, partly due to the fact that the research results could not be appropriately publicised, and partly that some unforeseen problems arose. The problems which occur nowadays in buildings, and which are together called the problems of the "Sick Building Syndrome", are often caused by moisture in the building and construction materials. It is therefore imperative that the necessary information is sought so that "healthy buildings" can be built. Continuing advances within the research area of building physics is therefore extremely well motivated. The universal aim of the research being undertaken at the department is to provide a basis of knowleldge so that energy-efficient, healthy and well-functioning houses can be built, thus conserving resources. Research is being carried out within the following four areas:

- the development of calculation models and theoretical analyses of heat-, air- and moisture transfer (a special group of researchers)

- the accumulation of information and the building up of the methodology for the design of buildings concerning moisture. (This work is being carried out within the Moisture Group at the Lund University.)
- research on heat insulation, and the design of sections of buildings and whole buildings from the point of view of the requirements of building physics, and energy conservation.
- research on plaster and brick-walls

Within each subsection fundamental subjects,which can provide a good basis for research, are studied.

Present Research Projects.

- PC models for mechanisms within building physics.The development of a new generation of computer models for heat flow in building design is underway. Parallel with this a corresponding development of models for the calculation of moisture mechanisms is being undertaken. Furthermore, models connecting these two mechanisms, as well as the effect of air movements are being modelled by these PC programs. The aim of developing these PC models is that they can become a natural tool in the design of buildings from the point of view of heat and moisture transfer.
- Thermal analyses of ground heat. In collaboration with the Department of Mathematical Physics, a research group is working on ground-heat systems , i.e., systems for heat storage in the ground, in ground water and in water, as well as systems for extracting heat out of soil, rock and ground water. At present computer models are being developed, in which heat stores, heating systems and economy are combined. A number of field studies are in progress. In the laboratory, measurements on different ground-heat exchangers are being carried out.
- Temperature mechanisms in the ground under a building. In particular slab foundations, foundations with crawl-space and buildings with cellers or basements are being studied. The aim here is to arrive at simple methods that make direct calculations, using equations and diagrams, possible for estimating temperatures, heat losses and the necessary depth of the foundation.
- Design for moisture. This implies the design of buildings without problems from moisture, by calculations, assessment and on the basis of experience. This can be compared with structural design, for example. In this way it is also possible to publicize up-to-date information on moisture in building construction to the building trade. The project has as its goal the development of methods that facilitate the treatment of moisture problems in the building process, both during the construction and at the designing stage. The application of the technique of designing begins with roof constructions and slab on ground foundations. There is always a certain risk of damage. With moisture designing one also aims at being able to make a risk analysis which would make it possible to anticipate the risk of moisture damage. An economic evaluation of this risk can then be made, and can be incorporated in the assessment of the choice of construction.

- Methods of repair for slab on ground foundations. Over the past few decennials, slab on ground foundations have been the most widely used foundations, at least for one-family houses. Many of these buildings show the effects of damage by moisture and mould. Within this project, the most common methods of repair have been studied by measurements in buildings both before and after the repair. Numerical methods of calculation have been developed to simulate the conditions in the construction concerning temperature and moisture after the repair. So far slab constructions of a limited width have been studied. In future, projects to investigate the problems of slabs of large areas will be taken up for special study. Furthermore, studies are to be undertaken of local disturbances such as the effects of heat culverts, different slab thicknesses in conjunction with loading, the effect of different indoor temperatures in neighboring buildings, etc.

- Foundations with Crawl-space. Crawl-space ventilation with outdoor air, with wooden joists, are prone to moulding and are a problem demanding increasing attention. In order to find the causes and to remedy them, extensive studies and calculations of temperature, the moisture conditions and ventilation of modern crawl-spaces are in progress.

- Brick walls. Within this project the construction of outer brick walls is studied from the prerequisites of building physics. In field studies, follow-up investigations of frost-damaged facades are being made. In several experimental houses extensive physical measurements are being carried out, in which, among other things, the function of the air space is studied. Methods of impregnation, which are an attempt to protect brick facades against moisture, are being studied and assessed in full-scale experiments.

- Heat- and air flow in thick insulation. Heat insulation that functions as it should is prerequisite the basis for an energy-efficient house. In order to be able to establish the best heat dimensioning from a technical point of view, it is important to know the heat losses through structures of thick insulation, and to increase our understanding of how these structures function in practice, so that the design can be carried out correctly. Small air movements, which lead to convective transport of heat , can produce large local disturbances of the heat flows, because these are small in highly insulated constructions. In order to be able to assess the risk of high moisture content, it is important to know the indoor climatic conditions of the section of the building. The currents that can be expected to arise are studied by accurately evaluating the construction and the building techniques used, in practice. Commonly occuring disturbances are simulated in the laboratory and are compared with theoretical calculations.

- In collaboration with the building industry, research results are applied in practice. This requires that new ideas in construction are developed, and are evaluated theoretically, in the laboratory and in full scale, experimentally and in demonstration buildings. It is particularly important that good solutions concerning details can be adapted to the whole building system and also to the production process.

Information

The results of the research are publicised in many different ways. A continuous dissemination occurs via the teaching programs at the university, both in the basic study course and at the research level. A natural and well-established course is the publication of reports and scientific articles in Swedish and international journals. A more active spread of information goes via the participation of members of the staff in international collaborations, e.g. International Council for Building Research Studies and Documentation, CIB and International Energy Agency, IEA. Further, we are also involved in standardization work in Sweden in The Swedish Building Standards Institution, in Europe in European Committee for Standardization, CEN and worldwide, within International Organization for Standardization, ISO. The department also contributes to the spread of information by giving courses and in the capacity of consultants, in preparing material for various purposes, e.g. about Healthy Buildings, Indoor Climate and Energy Conservation.

Examples of published reports from Dept. of Building Physics during 1991

Arfvidsson et al 1991
Heat and Moisture Transfer in Buildings - Research papers 1990. Report TVBH-3016. Dept. of Building Physics, Lund

Harderup, L-E 1991
Concrete Slab on the Ground and Moisture Control - Verification of some Methods to Improve the Moisture Conditions in the Foundation. Report TVBH-1005. Dept. of Building Physics, Lund

Wallentén, P 1991
Steady-State Heat Loss from Insulated Pipes. Report TVBH-3017. Dept. of Building Physics, Lund

Nevander, L E 1991
Moisture Dimensioning of Wooden Structures - Riskanalysis. Report R38:1991. The Swedish Council for Building Research. (Only in Swedish.) (Fuktdimensionering av träkonstruktioner - Riskanalys. Rapport R38:1991. Byggforskningsrådet, Stockholm)

Fuktgruppen vid LTH 1991
Moisture in Buildings and Material. Research 1987-1990. Report R7:1991. The Swedish Council for Building Research. (In Swedish Fukt i byggnader och material. Forskning 1987-1990. Rapport R7:1991. Byggforskningsrådet, Stockholm)

For further information, please, contact Prof Arne Elmroth, tel +46 46 104645 or Ms Birgitta Salmi, secretary, tel +46 46 107385.

Address: The Lund University, Dept. of Building Physics, P O Box 118, S-221 00 LUND, Fax nr +46 46 104535

Bertil Pettersson
The Swedish Council for Building Research
Sweden

INTERNATIONAL PERSPECTIVE OF BUILDING PHYSICS SUPPORTED BY THE SWEDISH COUNCIL FOR BUILDING RESEARCH - Symposium in Lund 1991-09-13

International cooperation is especially important today in view of the rapid changes and challenging development of the new Europe.

Last year the Swedish Parliament adopted a new Research Policy Programme which more than ever before stressed the importance of international contacts and international cooperation.

A recent government survey on the Council's future responsibilities also strongly emphazised the necessity of a well developed international cooperation.

Amongst the motives for a well developed international cooperation I would like to mention, for instance, the rapid technological development and the necessity to keep up-to-date with what is happening outside Sweden.

A high quality in the national R&D activities is important in order to take part in international research cooperation.

In order to ensure a high quality in the national research it is important to keep up-to-date with what is going on in other countries. To that effect, the Council finances so-called "building research attachés" in a number of countries regarded as specially interesting for Sweden. At present such "building research attachés" are placed in Paris, Bonn, London, Brussels, Los Angeles and Tokyo. They are not only responsible for informing the "home front" about new trends and developments in their respective countries but also for disseminating information in "their" countries about Swedish building research.

Cooperation within international organisations

International cooperation is an old tradition in the Council's activities and it keeps developing.

The amount of money which is invested in the Council's international cooperation is in the range of 30 MSEK. The total R&D budget is approximately 240 MSEK per year.

The Council has, throughout the years, set up an important network of international research contacts. These contacts are mainly established through an active participation of Swedish researchers in a number of international organisations such as CIB, IEA, the UN network of organisations like ECE and others.

There is, of course, also a well developed cooperation between the Nordic countries within the frame of the Building Research Organisations in the Nordic Countries - NBS. A well defined R&D research cooperation between the neighbouring Nordic countries is especially important as a basis for Sweden's future participation in various R&D programmes of the European Community.

Sweden also takes an active part in several IEA Annexes such as End Use Technologies where such specific areas as Energy Conservation in Buildings and Community Systems, Advanced Heat Pumps and Energy Storage can be mentioned. Important contributions have also been made in the Annexes for Renewable Energy especially in the field of Solar Heating and Cooling.

Recent years' R&D in the field of energy conservation in the built environment and new low-pollution energy systems - for instance solar collectors, heat pumps and seasonal heat storage - have resulted in an internationally important fund of knowledge. Swedish researchers have made many valuable contributions in the field of energy efficiency through a fruitful exchange of experiences on a national as well as on an international level.

Healthy Buildings - international cooperation

Healthy Buildings is another important research field given high priority in the Council's current activity plan. It is very important to arrive at hygienic and technical solutions that provide us with healthy buildings in which to live and work.

In the field of Healthy Buildings moisture research is a common denominator. Increased knowledge about moisture and moisture transfer in building materials is necessary to design and construct healthy buildings and ensure a good indoor climate.

A prerequisite for constructing healthy buildings is the development of practically applicable design methods from the aspect of moisture, air tightness and ventilation.

The faults and shortcomings encountered in consequence of new designs, new materials and so on constitute an international problem and international cooperation is essential if we are to make rapid progress.

One step to collect international knowledge and experiences in the field of Healthy Buildings was taken by the Council when an international CIB conference on Healthy Buildings was organized in 1988. The conference gathered the world' s expertise on indoor climate, and the main objective was to establish recommendations on choice of materials and systems to make buildings healthier. Another Healthy Buildings CIB-conference will be held in Hungary in 1995.

Theories with practical applications

I would now like to connect these rather general comments on the Council's international activities to the specific field of Building Physics where Professor Nevander has played an important role for instance in the areas of timber structures and moisture research. Professor Nevander's work has concentrated especially on such connected areas as heat insulation and air tightness of buildings.

In all those areas Professor Nevander has provided a valuable basis for future development both on a national and an international level.

Professor Nevander has taken an active part in various R&D projects to develop practical design rules in order to avoid moisture damage in buildings. He has also in a fruitful way inspired a number of researchers to important contributions in various fields of R&D.

The guiding principle in Professor Nevander's work has always been to combine good theories with practical applications.

Building Physics - a base for building technology

The importance of giving continued support to R&D in the field of building physics is emphasized in the Council's current three year activity plan. Building Physics is a prerequisite for development in other fields such as building materials and building construction as well as in the fields of healthy and energy efficient buildings.

The objective is to increase the knowledge and to improve and develop technologies so that building materials and constructions meet with society's high demands for safety, hygiene, durability and energy conservation to the lowest possible life-cycle cost of the building,

Finally, I would like to take the opportunity of thanking Professor Nevander for his valuable contributions to Swedish building research - contributions which also have been of a great international importance and I wish him a lot of luck in his future activities.

The Swedish Council for Building Research

- is a sectorial research agency funded by state grants under the auspices of the Ministry of Industry and Commerce.

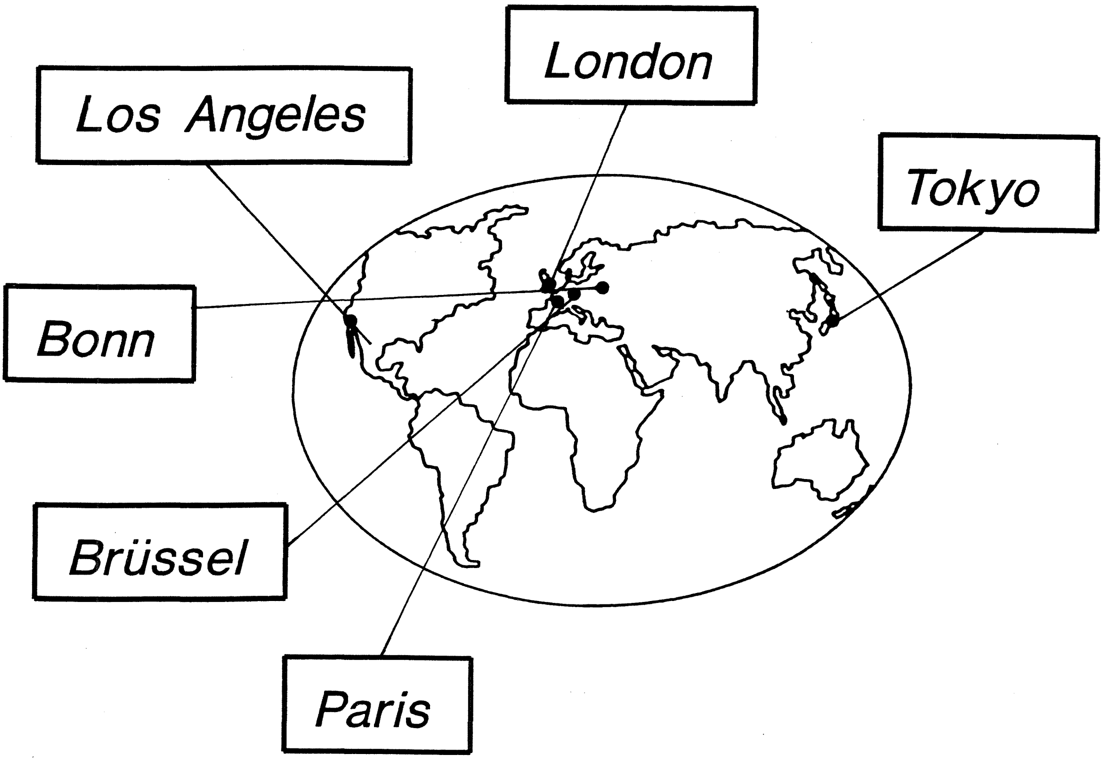
- is responsible for overall planning, coordination, funding and evaluation of research and development in the planning, building and housing sectors.

- has a budget of about MSEK 242 for the fiscal year 1992/93.

R&D regarding the built environment

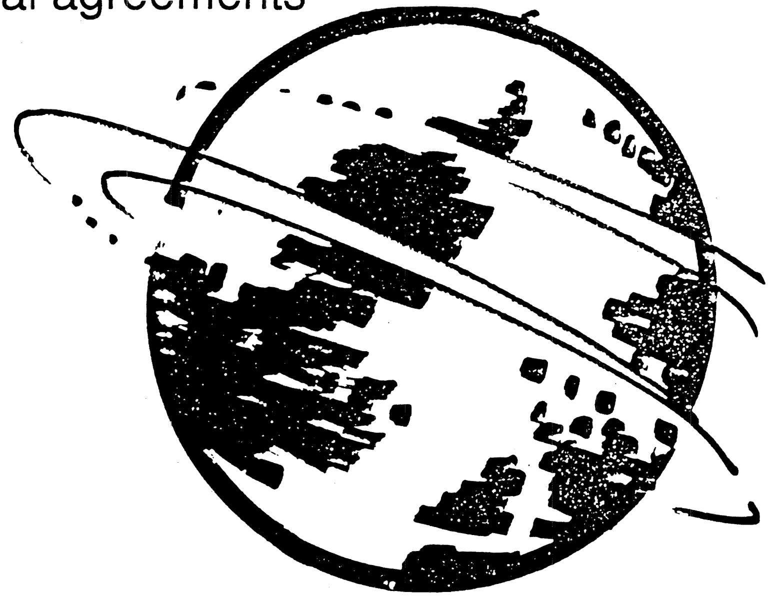
"R&D activities regarding transformation and design of the built environment by means of community planning, construction and management."

Our Building Research Attachés



International co–operation

- CIB
- ECE
- IEA (the International Energy Agency)
- NBS (the co-operation group of the Nordic building research agencies)
- Bilateral agreements



Gunnar Anderlind
Gullfiber AB
Sweden

THERMAL INSULATION MEANS ENVIRONMENTAL PROTECTION

Imagine a life without any motor vehicles!

There would be no cars, trucks, aircraft, motorbikes, motorboats... Not a single motor driven vehicle intended to carry people from here to there whatsosever.

Would we really survive in a society like that? Would we ever get used to it? The situation is hard to even imagine. It would be like taking ourselves a 100 years back in time. Nothing would work any more.

However, the environment would benefit from a drastic reform like that. The air pollution from CO_2, SO_2 and NO_x would decrease by about 35 %.

Are there other ways to get the same result? Yes, if we could replace all the energy that is heating our homes and houses with "clean" energy, not produced from fossile fuels, we would achieve the same effect. Without giving up any of our comfort and flexibility!

Domestic heating and heating of small commercial premises produce equally as much environmentally damaging pollution as the transport sector does.

Unfortunately, this way is as impossible to carry out as the first suggestion, as long as we don't increase nuclear energy production enormously.

My message today is the third way. Because there is a way to go without either yielding to nuclear power increase or attacking our comfort.

There is a way to reduce heating our houses with fossil fuels. We have to build and rebuild our houses with an optimal amount of thermal insulation.

Would that make a considerable contribution to the prevention of air pollution? Yes it really would. This is shown in plain figures in a report from EURIMA, the European Insulation Manufacturers Assosiation.

I intend to present some of these statistics and figures to prove this theory, which in fact is not only a theory: we have seen it work for a long time in lots of buildings in Sweden over the last few years.

But before that, let me remind you about another current environmental development: the greenhouse effect. It has, as a matter of fact, a close connection to thermal insulation.

Global warming is perhaps the most dramatic threat to our environment at present. Scientists specializing in climatic research talk about an increasing climatic catastrophe. What in fact creates this effect?

Well, certain gases, mainly carbon dioxide (CO_2), influence the atmosphere and reduce its capacity to reflect longwave radiation from the earth. Actually this makes the atmosphere work like an ordinary window: it lets the shortwave sunligt pass through, but absorbs the longwave radiation.

The effect is a global increase in temperature. This so called global warming can now be measured, and the result is alarming.

Scientists do not quite agree about either the speed of destruction in the atmosphere or the effects of it. But one thing is inevitable; there is an incredible environmental breakdown, which produces a so called greenhouse effect. And still worse, this development is irreversible. The damage done will never be repairable.

The immediate result from the greenhouse effect is an increase in the global temperature. Many people in Sweden will perhaps enjoy it in the short term. However, as a result of this higher temperature the polar ice caps will melt. This might raise the water level in our oceans by several meters, enough to simply put vital parts of even some Swedish cities under water, among others Gothenburg and Helsingborg.

Scientists expect the year 2050 to show twice the CO_2-concentration of preindustrial times, which would increase the average temperature by between $1,5^o$ and $4,5^o$ centigrade. While there are different opinions regarding the amount of temperature increase, there is no doubt that even a 1^oincrease in the average earth temperature has to be considered a dramatic development.

The main cause of the greenhouse effect is an excessive release of carbon dioxide (CO_2) into the atmosphere. It is a colourless, non-combustible gas, produced when fossil fuels such as gas, coal or oil are burned.

The industrialized nations of the world release enourmous quantities of CO_2 into the atmosphere every day. Between the turn of the century and 1985 the concentration of carbon dioxide in the atmosphere has increased by more than 20 % (from 290 to 348 ppm).

But there is another important factor which is influencing the rapidly increasing figures in carbon dioxide concentration. It is the enormous deforestation, especially in the tropical parts of South America. As we learnt in school the forests do a great job in absorbing CO_2 and producing oxygen. Now the deforestation results in an increased carbon dioxide concentration in the atmosphere.

And furthermore - lots of forests simply die from excessive SO_2-levels in the air. As SO_2 is also produced by burning fossil fuels, this is another disadvantage of domestic heating, which threatens the environment. As a matter of fact SO_2-pollution contributed by domestic heating is ranked ahead of vehicle exhaust pollution, whose effects can be partially eliminated by using catalytic converters.

While scientists and people involved in different types of environmental protection cooperate in their activities, one area has received insufficient attention so far: domestic heating. This area is still able to make a major contribution to cleaner air.

Compared with other pollution producers, domestic heating has the capability to reduce its damaging effects by simple and low cost means. And this might be carried out in a short time, without preceeding planning and complicated procedures.

The name of the game is thermal insulation. The question is: How large is the potential for lowering CO_2-emissions by building new houses and rebuilding old ones with optimal insulation thickness.

Let us look at these figures. The countries represented in the diagram are all members of EURIMA. Three Central European nations produce almost all of the CO_2-pollution in Western Europe. The sources of the emissions are collected in four groups: Power plants, Households, Traffic and Industry. One interesting fact is that Denmark has more carbon dioxide emissions from power plants than France, even though the total level of CO_2-emissions from France is four times as high as those from Denmark.

Look at this diagram. It is the same as before, but this shows the potential for decreasing the emissions. The three largest nations have the greatest potential. Sweden, Norway and Denmark have almost no potential at all.

These figures might not look too encouraging. But when we look at the possibilities in a diagram showing CO_2-emissions caused by domestic heating only, we see another picture. The potential for lowering the emissions in the three largest nations is remarkable.

And even more remarkable is the total European possibility for reducing CO_2-emissions by means of better building insulation. The EURIMA-report shows that 310 miljon tons of heating-related emissions could be avoided every year by applying state-of-the-art thermal insulation measures to new and existing buildings. That represents some 50 % of the total heating-related emissions and well over 10 % of the total CO_2-emissions in Europe! Eastern Europe is excluded in this EURIMA survey. And energy problems are still more severe there but I have no figures to show.

Let´s look at it from another point of view.

The total amount of CO_2 emitted into the world's atmosphere is approximately 20 billion tons. Ot this the EURIMA member countries account for 3 billion tons.

Households and small business alone accounted for a quarter of the amount.

Depending on the climatic conditions in the individual countries, 60 - 80 % of these emissions were related to heating.

The remaining 600 million tons for heating-related CO_2-emissions could be cut dramatically by the application of improved thermal insulation in the EURIMA countries.

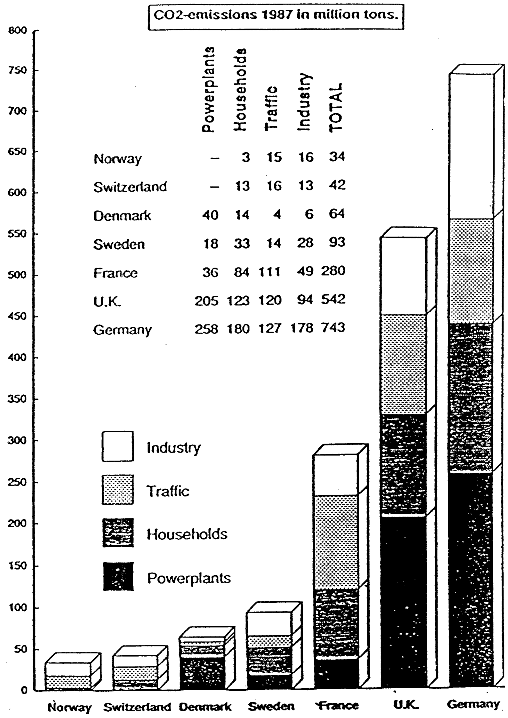
In addition to this, we have the effects of the SO_2-emissions. The total amount emitted in Europe is 13 072 million tons per year. In addition to being responsible for the major part of the CO_2 pollution, Mid-European countries produce the major part of the SO_2-emissions. Depending on the level of insulation, these emissions can be reduced by between 25 and 60 %. This would without any doubt be a considerable contribution to preventing further deforestation in Europe.

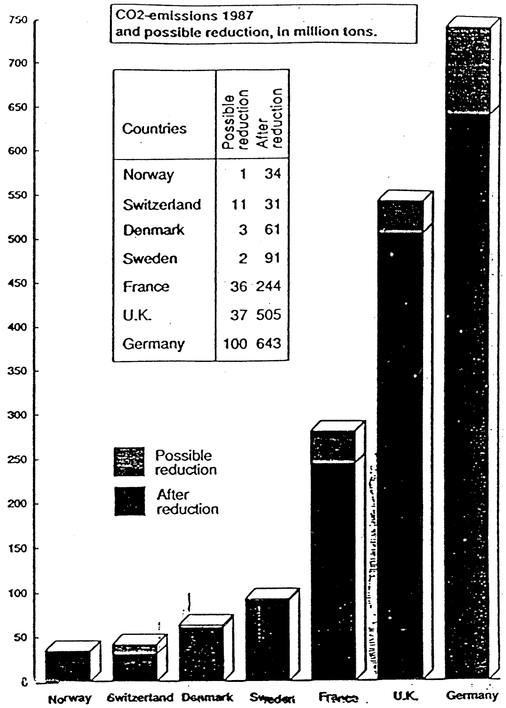
So, what are we waiting for? We are heading for a drastic situation with the most serious environmental threat ever to the earth. The serious messages about global warming and the greenhouse effect call for immediate action. A large responsibility rests on Europe, not only for contributing to a considerable part of the total pollution, but for having better opportunities to deal with the problem than most of the other parts of the world.

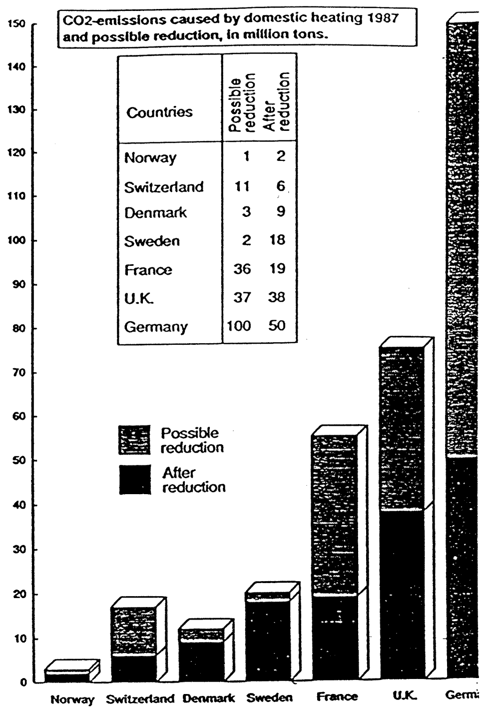
Europe must use all available chances to reduce the threat of a climatic and environmental catastrophe. Some of these possibilities will require less comfort and flexibility from the inhabitants, some will cost a relatively large amount of money, some would lead to other disadvantages.

But there is one way, which combines a large potential for reducing pollution, an even higher level of comfort, lower costs for heating energy and healthy green forests in Europe - better thermal insulation in building and rebuilding.

Obviously this must be a primary step in preventing environmental pollution. Because today we know the facts: Thermal insulation really means environmental protection!


CO2-emissions 1987 in million tons.
Powerplants Households Traffic Industry TOTAL
Norway – 3 15 16 34
Switzerland – 13 16 13 42
Denmark 40 14 4 6 64
Sweden 18 33 14 28 93
France 36 84 111 49 280
U.K. 205 123 120 94 542
Germany 258 180 127 178 743
Industry
Traffic
Households
Powerplants
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Norway
Switzerland
Denmark
Sweden
France
U.K.
Germany


CO2-emissions 1987
and possible reduction, in million tons.
Countries Possible reduction After reduction
Norway 1 34
Switzerland 11 31
Denmark 3 61
Sweden 2 91
France 36 244
U.K. 37 505
Germany 100 643
Possible reduction
After reduction
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Norway
Switzerland
Denmark
Sweden
France
U.K.
Germany


CO2-emissions caused by domestic heating 1987
and possible reduction, in million tons.
Countries Possible reduction After reduction
Norway 1 2
Switzerland 11 6
Denmark 3 9
Sweden 2 18
France 36 19
U.K. 37 38
Germany 100 50
Possible reduction
After reduction
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
Norway
Switzerland
Denmark
Sweden
France
U.K.

Ronald P. Tye
Sinku Riko, Inc.
USA

Thermal Performance of Insulation Materials and Systems: A Retrospective Review

INTRODUCTION

This contribution is a retrospective evaluation of over forty years of direct involvement in the subject of thermal measurements. Overall, this period has provided the author with the opportunity to utilize this thermal measurements experience internationally with a very large group of people involved in industry, government and academia. These also include national and international standards development organizations and it is with the latter, namely the formation of ISO TC 163 on Thermal Insulation in 1976, where he had the privilege of meeting and subsequently working with Dr. Lars-Erik Nevander, our honored guest.

A very noticeable change has taken place during this time. It is a radical change since it has involved what property we need, why we need it and how it can be evaluated. Overall it can be summarized as being the result of a combination of six specific changes:

- conceptual change of thermal insulation performance.
- improved understanding of heat transmission mechanisms.
- systems and applications becoming the driving force.
- need for more rapid measurements
- developments in instrumentation
- need for standardization

The subject has changed radically from being essentially an academic exercise in the laboratory providing limited data for reference books and materials specifications, to a complex issue generating necessary data for performance in many applications, for materials, systems, quality control and assurance and for conformance to national and international regulations.

The following discussion treats the above issues in a very subjective, general and somewhat historical context based on personal involvement and experiences during this time. It discusses the issues, methods and techniques that are now in most general use and includes recommendations for the future. It does not attempt to be comprehensive by any means.

HISTORICAL REVIEW

1. To 1950

While thermal insulations have been used, particularly, in and on buildings for centuries, initial interest in measurement of thermal performance can be traced to the early nineteen hundreds. At this time, the first guarded and unguarded plate and disk methods were developed for measuring the thermal conductivity of solids. During the next three decades, thermal insulation became much more widely used, especially for industrial applications at high and low temperatures, but developments of and improvements in measurement techniques followed much more slowly.

Most of the early analytical and experimental work described, related to the use of the hot plate method[1] at or near room temperature. Furthermore, theory and analysis were applied to most materials, assuming phenomenological processes in homogeneous isotropic media. Results on insulation materials and products were always presented as a solid thermal conductivity irrespective of the fact that other heat transmission mechanisms, including radiation, gas conduction, and mass transfer, could also occur. Apart from a limited number of special cases, very few measurement approaches were driven by applications issues.

1950 to 1960

During this period, several of the new technologies, stimulated by World War II, were beginning to impact everyone by applications to peaceful uses. In the thermal insulation field, cellular plastics using low thermal conductivity blowing agents to provide good thermal performance were in the development stage. Furthermore, fibrous insulation materials were being developed at lower densities to provide optimum performance based on both cost and thermal performance. New processes were required necessitating higher temperatures with corresponding use of high temperature insulations, particularly for piles. In addition, more consideration was being given to the concept of insulated systems used for the building envelope necessitating a need for a method to evaluate wall and roof components. These two applications spurred development of the pipe test (radial flow) method[2] and the guarded hot box method[3] for building components respectively. The calibrated hot box was a much later development for the latter requirement[4].

However, a more critical issue was the so-called technology explosion, resulting in a significant increase in materials to be characterized. Results, even for limited temperature and/or environment ranges, were needed quickly. Thus, much more attention began to be paid to the use of transient techniques including quasi steady-state line source [5]. However, while being more suitable for some solids, these transient techniques were found to be less applicable to the more homogeneous thermal insulation materials. Some very initial work at room temperature using the heat flow meter method[6] did show distinct promise in reducing the time of measurement to the order of 1 or 2 hours per specimen, rather than 8 to 10 required for the hot plate.

1960 to 1980

During the early part of this decade, there was the subject of very significant increase in the number of workers, often less experienced, who became involved in thermal measurements. In addition, commercial instrumentation was being developed for their use. However, this was tempered by the fact that there was a realization by the growing numbers of active workers in the subject that serious measurement problems existed in many areas and that precision claims were often inflated.

As a result of the efforts of a number of devoted workers, the early nineteen sixties saw the birth of regular national and international meetings devoted solely to the subject of thermal measurements and particularly to improvements in measurement technology. In addition, two books were published covering basic transport mechanisms[7] and methodology[8] respectively. Much more national and international cooperation resulted, especially in the standards development process. This included the formation of the International Committee ISO TC 163 on Thermal Insulation with Lars-Erik Nevander as the first chairman. During the subsequent years of the 80's, appropriate thermal test methods have been developed based now on this broad international experience.

However, to the author, this is the period during which the subject changed most radically due to the occurrence of two highly significant events:

The first was the development of stable thin, negligible thermal resistance, heat flux transducers of suitable areal size, that could be used in the previously mentioned heat flow meter method(9). In addition, types of high density fibrous glass material became available from NPL in the UK and NBS (not NIST) in the USA for use as reference materials necessary for the in situ calibration of the heat flow meter apparatus. The method has three attractive features:

- relative simplicity - a flat uninstrumented slab.
- speed of operation - tens of minutes instead of hours.
- virtual elimination of heat losses - due to the in situ calibration at the test conditions.

This first larger size transducer was a hand made artifact based on a regular woven ribbon thermocouple array within a phenolic based former. This integrated area type was in contrast to the then existing much smaller commercial forms which were less homogeneous as they consisted of strips of high thermal conductivity sensors distributed within the low conductivity matrix. Improved larger, thinner transducers are now manufactured by a photoetching technique and are used for a variety of laboratory and field applications(10), but particularly for heat flow meter apparatus.

The second and most decisive event was the impact of the energy crisies of the early and late seventies. These stimulated the use of more and thicker thermal insulation products. The use of the latter, especially for building envelope applications, indicated that the existing methods and apparatus were not totally adequate for the times. Much work was carried out to obtain a better understanding of the heat transmission modes to ensure that products were developed and used correctly and economically. Radiation and gas conduction modes dominate the heat transfer process in heterogeneous materials and the term thermal conductivity was seen to be not truly applicable. The thermal resistance concept became more widely used and is now universally accepted.

A special requirement was related to the need for reliable thermal performance measurements on low-density fibrous and cellular insulations, which were becoming utilized in thicknesses well in excess of 25mm. This had been a thickness widely used for previous measurements of thermal "conductivity" by the hot-plate method. It soon became apparent that such materials, due to inhomogeneity, variability, and the "thickness" effect due to radiative heat transmission(11), needed to be evaluated using a larger apparatus on a full or a "representative thickness. Additional reference materials transfer standards were also necessary in order to calibrate the larger systems(12).

Thermal performance became a necessary quality assurance/quality control tool for insulation products. In this environment the heat flow meter became the "method for the moment". While there had been limited development of the commercially designed instruments based on the hot plates and heat meter methods during the mid-sixties, especially for space related applications, this increased need for relatively simple direct-reading instrumentation became a major driving force in the further commercialization of thermal performance measurement. Evaluation of highly inhomogeneous thermal insulation products was transferred from the confines of the controlled environment laboratory to the manufacturing plant using less skilled and knowledgeable personnel. Rapid measurements by simple direct reading instrumentation became necessary using larger apparatus capable of measuring specimens ten times thicker than the commonly used 25mm. During this decade and into the following one, it is estimated that well over one thousand heat flow meter apparatus, including over 700 commercial instruments of different sizes and forms, went into operation. The majority of these remain in use both for plant and laboratory research use.

The heat flow meter method also became the most useful tool for use in studies of the aging characteristics of closed cell cellular plastics containing low thermal conductivity blowing agents to provide high thermal resistance products. The speed of operation combined with its value in "comparative" measurements, on the same specimens(13), allowed many more tests to be undertaken more rapidly, thereby providing improved understanding of the phenomenon and the contributions of the various heat transmission modes.

1980 to 1990

This decade may be considered as one of consolidation and continuing improvement, especially in the context of providing solutions to several emerging applications.

During this period, considerable attention has been paid to improved insulation systems to reduce energy consumption in appliances, especially refrigerators and freezers. More recently, this problem has been compounded by the fact that the currently used closed-cell cellular plastics containing fluorocarbon blowing agents are being restricted due to the deleterious effects of these gases on the environment. Although new blowing agents are being investigated vigorously using the heat flow meter method, and, no doubt will continue to be available in the future, serious consideration is being given to these hard vacuum metal panels and evacuated powder or aerogel filled systems as a viable alternative for the longer term.

Measurements on such systems are somewhat difficult due not only to the overall high thermal resistance of the panel, but also to inhomogeneity and lateral conduction along the metal and plastic skins and at joints and supports. One good technique appears to be the use of the large thin-screen heater self-guarded hot plate developed at Oak Ridge by McElroy and colleagues(14). A second is the so-called line-source heater form of guarded hot plate, first suggested and developed by Robinson(15,16). This has now been developed further as a lm diameter system at NBS, (now NIST) in the USA.

These types of large plate have been proven both analytically and experimentally (around 293K) to be capable of providing results of high precision. Their size make them suitable for evaluating complete panels, such as refrigerator door and wall panels. However, it should be pointed out that they have been verified using only the very limited "homogeneous" reference materials or transfer standards currently available. Such materials are of a much lower thermal resistance and their maximum degree of anisotropy is of the order of only 30% whereas that of the panels can be an order of magnitude and much greater.

The search for alternative blowing agents for closed cell plastics has added impetus to the development of a more suitable, less time consuming, accelerated aging tests to determine the long-term thermal resistance behavior and efficacy of products containing the agents. In general, current national standard methods involved measurements, at regular time intervals from some initial "zero" time, of the thermal resistance of a uniformly thick (25mm or greater) specimen(s) conditioned either at some controlled elevated temperature or at ambient room temperature. Depending upon the standard, the elevated temperatures have ranged between 60°C and 100°C and times varied from 90 to 10 days. Alternatively 180 days or longer at room temperature have been other criteria used.

The long term thermal resistance of the specimen is then determined from an extrapolation, based on some mathematical model, of the curve generated by plotting thermal resistance v time.

None of the above procedures has proven to be totally satisfactory as a generally accepted procedure for estimating long term thermal resistance. Furthermore, for some materials, in addition to increasing gas diffusion rates by an order magnitude heating at elevated isothermal temperatures for long periods of time, i.e., conditions not normally experienced by the material in use, can or may cause other changes in properties not associated with the aging process and thus provide incorrect information. However, more importantly current time restraints for the elimination of existing blowing agents by the mid-nineties, make such tests involving times up to 90 or 180 days totally unrealistic.

A Working Group of ISO TC 163 Subcommittee 1 on Test Methods, with the author as Convenor, has been working on the development of a new test. The philosophy of this test is to eliminate the elevated temperature parameter and condition thinner specimens at ambient temperatures for shorter times. This is based on original promising research work carried out originally in Scandinavia, and subsequently in Canada, on different types of cellular plastics at thicknesses of 10mm or less over much shorter time periods.

The proposed method is based on the two concepts commonly described as the "slicing" and "scaling factor" techniques. In the development of the method, the following parameters are addressed:

- techniques for preparing thin test specimens with inclusion of an allowance for the thickness of the damaged surface layer.
- measurement of thermal conductivity and resistivity of thin specimens, using ISO 8301 heat flow meter or 8302 guarded hot plate methods.
- a semi-logarithmic presentation of thermal resistivity v time combined with the use of scaling factors to allow correlation of aging of thin and thick layers of uniform (core) material to be undertaken in order to determine thermal resistance of aged products.
- a simplified test to determine a conservative value for use as a design lifetime performance figure for an unfaced cellular plastic product.
- suggestions for measurements on a faced or otherwise protected products.

A draft DP is in the ballot process. Similar developments are now underway in North America and are now being examined further by those involved in developing a suitable test for CEN requirements.

Because of the continuing and increasing requirements for certification of thermal insulation products, both nationally and internationally, there is need for measurement times to be reduced further. Currently, the basic heat flow meter method using one transducer requires a time of 15 to 90 minutes per specimen, depending upon its density and thickness.

Recent studies in France[17] indicate that these times can be reduced significantly using an apparatus very similar to a standard type of instrument modified only with an additional heat flux transducer and a separate heater circuit to heat the hot plate during the specimen change-over period. It has been verified analytically and also experimentally that an averaging of the outputs from the two transducers provides the same result as that for steady-state conditions using one transducer but in one-third to one-quarter of the time. The method will serve as an excellent means to improve products by reducing more immediately some of the variability due directly to processing. Furthermore, the technique lends itself to complete automation, since both the heating and the measuring times are known functions of thickness, density, thermal conductivity and specific heat of the test specimen.

The measurement techniques discussed so far have all been based on steady-state undirectional heat flow. While such methods are necessity to the subject, it is only on very rare occasions that a thermal insulation operates under steady-state conditions. This is particularly true for insulations used in buildings where the effects of the diurnal cycle can have significant influence. Ideally, therefore, there is a need for thermal diffusivity measurements, especially for insulation materials and systems, particularly to aid in verification both of performance models and of proposed field measurement methods which are in use or being developed.

Both the thin screen heater technique and the two heat-flux transducer heat meter method offer possibilities of measuring this performance characteristic. In the former, the heater has a very low mass and rapid response, such that its effects can be neglected. Thus, it should be possible to analyze the temperature-time response for a given power input and obtain the diffusivity directly. In the other method, it appears conceivable that thermal diffusivity can be measured directly from an analysis of the average of the transducer outputs with time, providing that the temperature of the plates can be controlled within very strict limits during the whole experiment.

The discussion so far has related primarily to measurements undertaken in the laboratory under "ideal" conditions. During the past ten years or so more efforts have been applied to the subject of field testing of materials, envelope components and ultimately buildings. However, such tests are time-consuming and very expensive to carry out correctly. Thus, before undertaking such testing, there is a need to ensure that sound measurement practices are employed. One way of approaching this is in the development of a standard test methodology to measure dynamic thermal performance of insulated systems using laboratory hot box methods. In this context, the slow ramp test technique first developed by Stephenson and colleagues at National Research Council in Canada for use with the guarded hot box appears to be highly promising[18]. Burch and his colleagues at NIST Gaithersburg, have now modified this in terms of a fast ramp technique for the calibrated hot box[19].

In these measurements, the insulated specimen is mounted between the two climatic chambers and allowed to equilibrate. It is then subjected to a ramp change of temperature on one side. For example, in the calibrated how box technique, the specimen is sandwiched between the metering and climatic chambers. The metering chamber is maintained at typical indoor conditions and is also being used as the calorimeter to determine the transient heat transfer rate. Once equilibrium has been attained, a dynamic excitation function, i.e., a fast ramp change from an initial to a final test temperature, is generated in the climatic chamber. The heat transfer response to this is analyzed to yield transfer functions coefficients which characterize the dynamic performance of the specimen. If the guarded hot box method is used, a slow ramp change is applied. Initial results on simple systems appear encouraging.

The increased use of cellular plastics in building envelope components has stimulated a need for understanding their overall contribution to performance under live environmental conditions. A variety of analytical models have been developed to predict performance[20]. However, as input, all models used steady-state data from isothermal conditioning laboratory tests on "small" specimens. Thus they need validation with accurate results developed from other tests, especially actual field investigations.

In this context, some results of a laboratory guarded hot box investigation on typical large panel roof and wall systems insulated with cellular plastics and including one with fiberglass batts as a control are worth mentioning(13). These panels were subjected to temperature and humidity differential exposures representative of typical winter and summer conditions as well as isothermal exposure for periods up to two years. Separate small panels of the identical material used in the systems were also subjected simultaneously to the same exposure conditions and measured at the same time periods using the same heat flow meter apparatus to eliminate apparatus variables. The general aging behavior was found to be similar for the materials and the systems containing the material. However the latter tended to age at a significantly slower rate. This is due in most part to the added protection of the coatings or the other surface coverings used in the respective envelope component system.

Results of actual field tests on cellular plastics have tended to indicate that the materials "age" much faster and attain much lower thermal resistance values than predicted from the results of laboratory investigations. Most of this testing used the so-called cut-panel technique whereby, at different times, specimens are cut from the component, transported to a laboratory and measured(21). Any changes in resistance value have been attributed solely to aging without consideration of other factors such as moisture, cycling, wear, poor workmanship, etc., which can affect performance.

However, this technique and in situ methods, such as instrumentated panels, are of little use unless the initial product is well characterized before installation and continued intermediate characterization is included on the test specimens themselves following their exposure. This author has outlined for roof studies the test protocols for in situ and cut-panel tests together with necessary characterization parameters required in order to obtain the true effects of aging(22). Currently, in the USA a joint Department of Energy/Society of Plastics Industry investigation is underway. Basically this follows the recommended characterization test protocol but does not include all of the necessary intermediate characterization.

As mentioned earlier, a preferred field measurement technique is that of the instrumented in situ panel. In North America, two guidelines relating to appropriate means of measuring in situ heat flux and temperature and then calculating thermal resistance values from the measurements, have been developed by ASTM C16. Currently ISO TC 163 is also developing a similar document which combines the two sets of parameters.

Overall, such measurements require considerable care in the design of the experiment, particularly with regard to the type and placement of heat flux, temperature and climate sensors, the calibration of the sensors, the length of monitoring periods of the data, time of year and the complexity of the data analysis. A recent cooperative effort (23) involving two different techniques developed especially for insulated roofs indicate that an accuracy somewhat better than 10 percent is possible. This two-year study was undertaken at the Roof Thermal Research Apparatus (RATA) at Oak Ridge National Laboratory. It involved two distinctly different experimental and analysis strategies using heat flux transducers on an insulated roof system. Both strategies conformed to the relevant ASTM guidelines for measurement and calculation.

The results were very encouraging in that agreement of 4 to 7% was obtained for times of the year when weighted mean temperatures were outside the approximate range 20 to 35C, i.e., when heat fluxes were very small. In this latter regime, differences of 10% and greater were experienced. One important factor of the comparison was that the two techniques exhibited the exactly same type of performance relationship with temperature and extent of property change with time and also agreement with laboratory measurements carried out separately on specimens of the phenolic insulation used for the study. As far as can be ascertained, this is the first occasion where two techniques have been validated by direct comparison and the development of such measurement strategies is particularly useful for in situ aging studies.

The study illustrated that reliable, reproducible measurements can be undertaken providing great care is taken in the experimental strategy, particularly in the calibration of heat flux transducers, etc., and the way that the data are analyzed. However, one of the major issues addressed is that worthwhile results can only be obtained with integration of collected data over long time periods and where significant heat fluxes are involved. This must also be accompanied by appropriate material characterization both before and during the relevant time periods. Obviously, this adds significantly to costs of tests.

1990-?

At this point early in the last decade of the present century it is prudent to evaluate the state-of-the-art to the extent that this can provide guidance for future activities. One criterion possible is to examine results of interlaboratory studies by different methods.

During the past ten or more years several such studies have taken place. These include a member involving both guarded hot plate and heat flow meter methods, undertaking measurements on fibrous and cellular materials usually at 24°C or other temperature in the range 10 to 25°C. These have included investigations under the auspices of ASTM in North America, the EEC in Europe and ISO TC 163 world wide.

Essentially, although all have a very few outliers in general, it appears that measurements by the hot plate method can be made to the order of ±2%. In all studies in North America, a similar order of precision has been attained with the heat flow meter method with little discernable bias, but with a much better reproducibility(24). In the ISO study the precision with the heat flow meter method outside the USA and Canada, is not as high being the order of ±6%. The overall reason for this is unknown, but it could be due to certain differences in some calibration procedures and more probably to the fact that the method has been used much more extensively for a longer period of time in North America.

At higher temperatures the picture is somewhat different. A high temperature guarded hot plate study involving some seven organizations was carried out on a high-density calcium silicate and a moderate density aluminosilicate fiber board up approximately 770K. This was undertaken both to evaluate the current state-of-the-art and to provide information to assist in the revision of the current C177 standard(25). While each experienced participant carried out the measurements very carefully, according to their interpretation of the standard, the results indicated a reproducibility of the order of 15 to 16%. This is considerably greater than 2 to 5%, which is claimed normally, albeit at lower temperatures. Thus there is a need to examine both the methodology and the apparatus design and analysis to evaluate areas where improvement can be made especially as the current pipe test method seems to provide much better results certainly up to 700K(26).

With regard to hot box methods, in North America some 20 organizations participated in a study using both guarded and calibrated hot boxes on specially prepared specimens of a well-characterized expanded polystyrene(27). Results were somewhat disappointing in that they showed approximately ±7% spread for this "homogeneous" material. In addition, there was a definite and, as yet, unexplained constant difference between the results of the guarded and those of calibrated boxes. Since hot box methods are used primarily to evaluate more complex insulated buildings systems containing thermal bridges and other anomalies, it is likely that the above accuracy will not be attained for such systems. Much additional verification and validation is necessary for such types of systems especially if hot-boxes are to be used as the basis for field testing technology.

However, it is worth drawing attention to one example of the degree of precision and reproducibility that can be attained. This can be done by referring to some results obtained during the building envelope component aging study mentioned earlier(13). One of the panels contained fiber glass batts which as far as we are aware does not age. Despite the fact that these insulated systems were transported 200km, a number of times, to and from Northaven, Connecticut where they were conditioned to our laboratories in Cambridge, Massachusetts, where they were measured the results on this panel over the 2 year period indicated that the precision was of the order of ±2%.

The line source method is still one technique being proposed as being applicable to measurement of thermal insulation, particularly in situ and for high temperature measurements. A recent study carried out at 24°C only on several materials, including three well-characterized insulations, Ottawa sand, and paraffin wax using the transient line-source method in various forms including the probe. The results of the study were not encouraging(28). They indicated standard deviations of some 20% for the different forms, differences of means values of 15 to 35% between the different forms, and differences of results in excess of 10% from current accepted values obtained by the guarded hot plate method. These results tend to reinforce the earlier comments that this technique is not really suitable for thermal insulations. This is true, especially when considered with respect to additional error source and practical issues of anisotropy, radiation heat transfer effects, and possible electrical conduction effects at very high temperatures, certainly indicate that considerable thought and effort must be expended before such a method can be utilized successfully with thermal insulations.

Although reference materials are not a panacea to solving all of our current measurements deficiencies and inconsistencies, the present discussion does highlight that more are required as discussed by the present author some years ago(12). There is a distinct lack of reference materials and calibration specimens for verification of primary and new methods and to calibrate the secondary techniques. In the latter category, the very widely used heat flow meter method is totally dependent on transfer standards. In particular, since the method is now being used or considered for use at higher temperatures, the need for calibration samples with known properties to at least 500K is now urgent. Furthermore, higher-temperature stable heat flux transducers are now being developed such that the needs are being extended even further.

Some work has been carried out at NIST in the USA on a microporous material and is it is now SRM 1459 at 393K. Work is also underway on an aluminosilicate board. However, these are insufficient. In addition, we still need reference materials or samples for the pipe test method, reference panels for the hot box method, while consideration must be given to the earlier discussed issue of precision of measurements on very high thermal resistance inhomogeneous panels .

There is no doubt that in the past three decades very great advances have been made in thermal measurement technology related to thermal insulation materials systems. One of the major contributors to this has been the continued developments of and improvements in electronic components, digital data acquisition and computer hardware and associated software.

In a number of cases, thermal measurements and related properties have become automated. Many new workers more oriented and interested in research and development on materials and their application than on methodology and instrumentation now need these properties on a daily basis. These two factors have contributed to the increased availability of automated commercial equipments both for stead-state and transient measurements. However, a word of warning from a member of a previous age. There are some disadvantages in the reliance of workers on automation of apparatus. It is still essential that the user have some appreciation of both the material(s) involved and the basis of good experimental procedure before accepting everything that appears on a computer screen, print-out or generated curve. As pointed out by Taylor[29] subtle errors in programming, for example, can escape detection for a long time and cause significant errors. Since programs are being constantly being revised, expanded and updated, continuous checks need to be made at all times.

With so many different techniques, methods and apparatus now in use by a variety of people, many of whom are less experienced in the field that those of us assembled there, the overall subject of precision must be addressed and only we can do so. It is very easy for us to claim, quite correctly, that these are difficult measurements to make and, there are so many parameters involved when one considers, thermal properties range, method, specimen size, form, temperature and environmental conditions, etc., etc., etc. Since the needs for reliable information exist as do the uncertainties, we cannot afford to rest on our laurels and accept the latter, particularly as we need to design and operate systems more efficiently for energy conservation purposes. This ladies and gentleman is our stimulus for this next decade.

REFERENCES

1. ASTM C177-42T, Current revision 1985, ASTM, Philadelphia, PA.

2. ASTM C335-54T, Current revision 1989, ASTM, Philadelphia, PA.

3. ASTM C236-60, Current revision 1989, ASTM Philadelphia, PA.

4. ASTM C976, Current revision, 1990, ASTM Philadelphia, PA.

5. van der Held, E.F.M. and van Drunen, F.G., 1949, Physica, 15, 865.

6. ASTM C518-63T, Current revision 1985, ASTM, Philadelphia, PA.

7. Missenard A., 1965, Conductivité Thermique, Editions Eyrolles, Paris.

8. Thermal Conductivity, Vols I & II, 1969, Ed. R.P. Tye, Academic Press, London.

9. Pelanne, C.M. and Bradley, C.B., 1962, Mater. Res. Stand. 2, 549.

10. Degennes M., Klarsfeld S., and Barthe M., 1978, in Thermal Transmission in Insulation, STP 660, Ed. R.P. Tye, ASTM, Philadelphia, PA, p. 130.

11. Jones, T.T., 1967, NBS Special Publication 302, 737.

12. Tye, R.P., Coumou, K.G., Desjarlais, A.O. and Haines, D.M., 1987, Thermal Insulation Materials and Systems, STP 922, Eds. F.J. Powell and S.L. Mathews, ASTM, Philadelphia, PA, p. 651.

13. Tye, R.P. and Desjarlais, A.O.,1987, Polurethane World Congress 1987: 50 Years of Polyurethane, Fachverband Schaumkunstoffe e.V. Frankfurt and The society of the Plastics Industry, New York, p. 91.

14. McElroy, D.L., Graves, R.S., Yarbrough, D.W. and Moore, J.P., 1985, Guarded Hot Plate and Heat Flow Meter Technology, STP 879, Eds. C.J. Shirtliffe and R.P. Tye, ASTM, Philadelphia, PA, p 121.

15. Tye, R.P., Nature, 204, 636, 1964.

16. Hahn, M.H., Robinson, H.E. and Flynn, D.R., 1974, Heat Transmission Measurement in Thermal Insulations, STP 544, ASTM, Philadelphia, PA, p 167.

17. Langlais, C., Boulant, J., and Darche, I., 1990, Insulation Materials Testing and Applications, ASTM STP 1030, Eds. D.L. McElroy and J.F. Kimpflen, ASTM, Philadelphia, PA, p 510-524.

18. Stephenson, D.G. , Private Communication.

19. Burch, D.M., Zarr, R.R., and Licitra, B.A., 1990, Insulation Materials Testing and Applications, ASTM STP 1030, Eds. D.L. McElroy and J.F. Kimpflen, ASTM, Philidelphia, PA, p. 510.

20. Tye, R.P., 1988, J. Thermal Insulation, 11, 196.

21. Zarate, D.A., and R.L. Alumbaugh, "Thermal Conductivity of Weathered Polyurethane Foam Roofing", U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA Report TN-1643, (1982).

22. Tye, R.P., 1988, J. Thermal Insulation, 12, 17.

23. Courville, G.E., Desjarlais, A.O., Tye, R.P. and McIntyre, C.R., 1990, Insulation Materials Testing and Applications, ASTM STP 1030, Eds. D.L. McElroy and J.F. Kimpflen, ASTM, Philidelphia, PA, p. 141.

24. Hust, J.G., and Pelanne, C.M., 1985, NBSIR 85-3026, NIST, Boulder, CO.

25. Hust, J.G., and Smith, D.R., 1988, NBSIR 88-3087, NIST, Boulder, CO.

26. Hollingsworth, M. Jr., 1978, Thermal Transmission Measurement of Insulation, ASTM STP 660, Ed. R.P. Tye, ASTM, Philidelphia, PA, p. 50.

27. Bales, E.L., 1988, "ASTM/DOE Hot Box Round Robin", DOE Report, ORNL/Sub/84-97333/2, November. See also Proceedings of Hot Box Operators Workshop, 1987, J.Test Eval. 15(3).

28. Hust, J.G., and Smith, D.R., 1989, NISTIR 89-3908, NIST, Boulder, CO.

29. Taylor, R.E., 1989, Thermal Conductivity 21, Eds. C.J. Cremers and J. Thomas, Plenum Press, New York, In course of publication.

Claes Bankvall
Swedish National Testing and Research Institute
Sweden

Thermal Insulation and Research in Heat Transfer

For a long time...

thermal insulation and heat transfer have been major areas of research in Sweden, and have played an important part in developing building physics. In the following I will touch upon questions of interest during the years. I will point to some results and also to remaining questions. This review will largely be based on work done at LTH under Lars-Erik Nevander. However, I think it gives a fair picture of general development in the area.

The material...

was initially considered to be the major problem. Walls and roofs were insulated with mineral wool insulation in the sixties. Deficiencies in the thermal performance of the building envelope were normally attributed to deficiencies in the insulating material. It was suspected that air movements within the insulation (micro-, macro- etc convection) were the reason for the problems.

From the beginning it was obvious that to be able to evaluate "would be" air movements, and their influence on the heat transfer in the material, it was necessary to have a basic understanding of the mechanisms of heat transfer such as conduction and radiation in the material. Perhaps the concept of thermal conductivity was not that simple. Perhaps it was not even relevant as a material constant. So, the first work was to develop a model for the mechanisms of heat transfer in a fibrous material. Mineral wool was an excellent material from a pedagogical point of view.

In a fairly basic model, the different types of heat transfer in the fibrous material were described: conduction in solid phase constituting the insulation, radiation in the material and heat transfer in the gas confined in the insulation. At the same time a one-sided, rotatable and evacuable guarded hot plate was designed to be able to study heat transfer in materials. Thus the influence of the mechanisms of heat transfer on the effective thermal conductivity was summarized as follows (Figure 1):

- Conduction in the gas contributes the largest part of the thermal conductivity in the range of density studied (15-80 kg/m^3).

- Radiation is of greatest importance for low density materials and leads to high values of thermal conductivity in these cases.

- Conduction in solids is important in high density materials where it can lead to an increase in the thermal conductivity value.

- Increasing the mean temperature of a material gives an increase in its thermal conductivity value. This is especially noticeable at low densities due to radiation.

The problem concerning convection within the material remained however. Deficiencies in the thermal performance were still attributed to this phenomenon. Natural convective heat transfer within the material was consequently the next problem to be studied. Mineral wool still remained an excellent material for research, and it also became increasingly used in the building envelope in the beginning and during the seventies.

Natural convective heat transfer...

was a well known phenomenon in the air space and when a permeable insulation was introduced in the airspace it was obvious that the resistance to air flow in the space would increase. So the specific permeability coefficient was introduced and the question was: how much is needed to stop any airflow? To be able to treat this problem a specific situation had to be defined - the insulated space. A numerical solution to the problem was developed in a range of interest to building technology applications. It was shown that natural convective heat transfer in the permeable (closed) space depended upon a modified Rayleigh number, the h/d aspect ratio and the boundary conditions (Figure 2). The Rayleigh number in its turn depends on the temperature situation, the material and the space dimensions. The problem was obviously dependent upon design and climate. Analyses with the model and experiments in the hot plate also showed that permeabilities, normally used in insulation materials at the time were such that relevant temperature situations and dimensions should not really give any noticeable influence on the heat transfer situation due to air flow in the material.

Experience from practice...

however, showed us that the insulated space seldom contained only insulation. Quite often there were air spaces and cracks around the material. Back to modelling and laboratory measurements. A typical insulated space was defined, and also deficiencies in the space (Figure 3). A special hot box was developed and modelling and measurements showed that substantial increases in U-value can be expected when thermal insulation installation allows air spaces and cracks in the space to be insulated. This was more or less independent of the permeability of the material. Now it seemed that the problem was turning into a workmanship problem.

From practice we also knew that complaints of low indoor temperature quite often related to windy situations. It was high time to evaluate, overall, the building envelope and the climatic load, i.e thermal insulation and airtightness.

The multilayer wall...

is essentially designed with a face wall that gives some protection against rain and wind, behind this an air space intended to transport moisture from the building envelope, a wind barrier that will protect the thermal insulation from air movements from the outside, the thermal insulation that gives the design its main thermal resistance and a vapour barrier that will stop moisture transport from the inside and give the wall its main airtightness (together with the inside board) (Figure 4). This means that the wind and pressure situation around the building give the conditions for air movements in the envelope. Choice of design and material will decide air flow resistance, the insulation material and the insulated space being of little importance.

Forced convection...

had to be dealt with. We were getting closer and closer to practice. Energy prices were increasing, and so was the thermal insulation thickness in the building envelope. Deficiencies in thermal performance were still blamed on the insulation material.

This led to the development of a model for air flow through channels and materials. Together with laboratory experiments on different parts of structures, air flow resistance and coefficients were measured. There was now some possibility of evaluating air movements. For various reasons, the accuracy was not all that great. One important reason was that the pressure situation in and around the envelope was not well known. A number of full-scale measurements were made. They had to be made at length because it was difficult to relate wind situation to pressure situation. The duration of the measurements became an increasing problem for the inhabitants. In the laboratory however, it was possible to show, by hot box measurements, the importance of wind protection, especially when the thermal insulation installation contains air cracks and air spaces (Figure 5). In a similar way, it was shown that deficiencies in the vapour barrier and the inside, constituting the airtightness of the structure, could lead to large amount of heat transfer, as exfiltration or infiltration of air was possible. Design solution and workmanship had decisive influence on the thermal performance.

In qualitative terms...

the total picture could now be formulated as follows:

The thermal performance of the building envelope depends initially on

- design solution, and
- thermal insulation.

The thermal resistance experienced in practice depends on

- the different parts of the envelope fulfilling their respective functions, and
- workmanship.

High thermal resistance is especially dependent on

- airtightness
- insulation installation, and
- wind protection, especially of "susceptible" areas.

So we decided that major deficiencies in the thermal performance depend upon workmanship and the design solution. At the end of the eighties, all this work even had some impact on the building regulations. originally, the building regulations treated the thermal performance problem as a pure material problem. All factors were considered to influence the material and led to a thermal conductivity to be used in practice. The current building regulations however, attribute the different factors to material, design or workmanship in a relevant way. Moisture and ageing being parameters influencing the material, and design solution, workmanship and climatic situation being major factors influencing the U-value.

Anything remaining?

Unbelievable as it seems, a number of activities are going on in the area. In the USA, convective loops are discussed, modellings are done for combinations of thermal material and air spaces, workmanship is discussed in the terms of cavities and voids and also in cracks, giving one U-value for the winter and another for the summer. In France, evaluations are done of interaction between thermal insulation and air volumes. In Norway, measurements and designs are discussed in terms of wind protection and practical U-values. In Finland, evaluation of convection in the building envelope and its influence on the total heat consumption are modelled and measured. In Sweden, a programme is under way under the heading "Thermal research in the field of building physics with application to buildings". Major problems are heat transfer mechanisms in the material, the performance of loose fill insulation, the interaction between the insulation and the air volume, probabilistic methods to evaluate the performance of the building envelope, practical U-values and design safety factors etc.

The final question seems to be: "Didn't we do anything, or can't they read?" At least we learned a lot. Let us hope they will.....

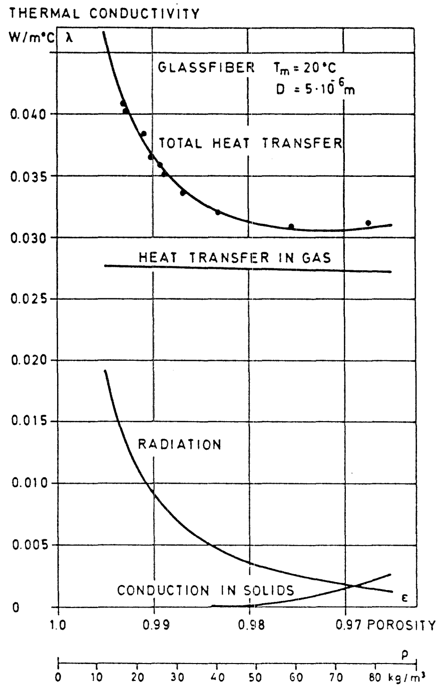


Figure 1 The mechanisms of heat transfer in a fibrous material
— = calculated and • = measured values

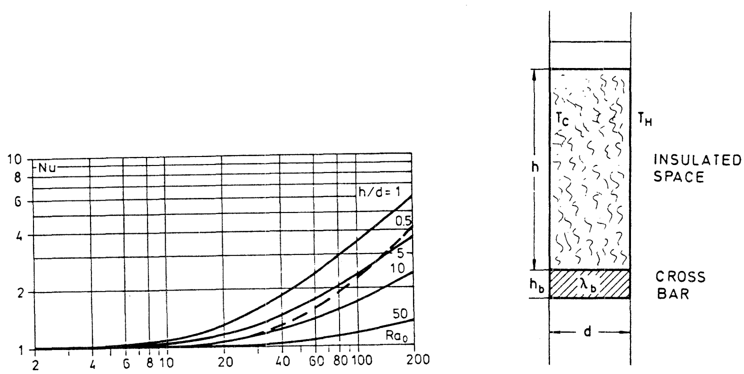


Figure 2 Natural convective heat transfer in permeable space with isothermal vertical and insulated horizontal boundaries

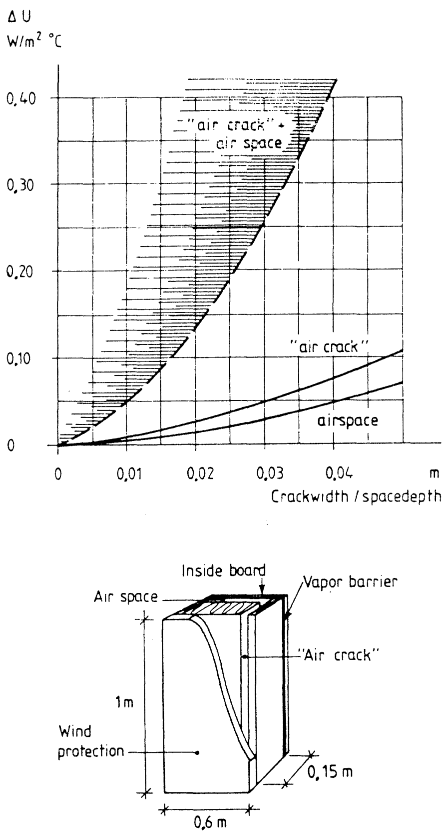


Figure 3 Increase in thermal transmittance thorugh a wall section with deficiencies in the installation of the thermal insulation

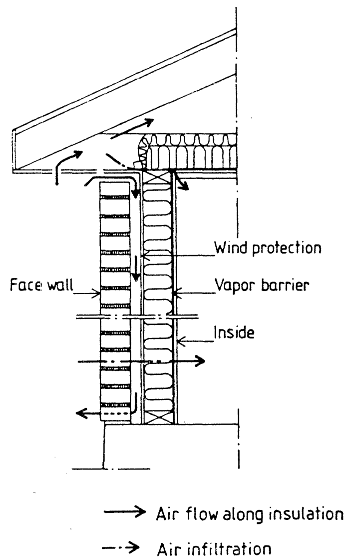


Figure 4 The building envelope, its ventilation and the parts that provide wind protection and airtightness

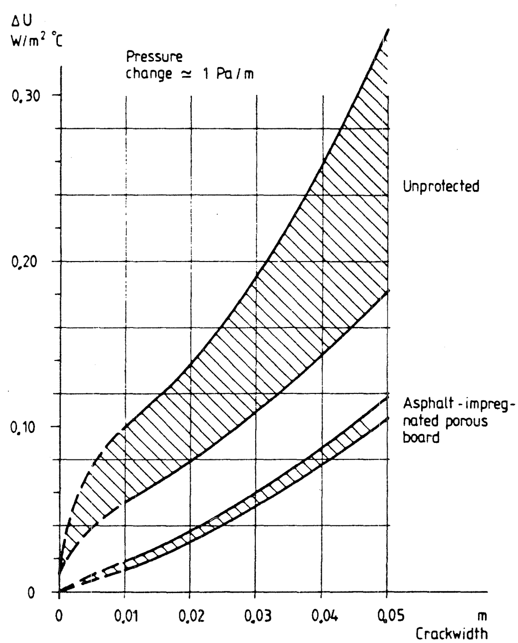


Figure 5 Increase in thermal transmittance of a crossbar wall due to air flow along the insulation and a vertical crack along one of the crossbars

Anker Nielsen
Narvik Institute of Technology
Norway

VALIDATION OF MASS TRANSFER CALCULATIONS

1. Introduction.

Mass transfer in building technology is the same as moisture transfer. Moisture can be transported in different forms as water or vapour or it can accumulate in the constructions. This gives the following problems with moisture calculations:

A: Calculation methods
We have simplified or complicated methods. All methods are normally based on certain assumptions of how the moisture is moved. This can be as diffusion of water vapour or as capillary flow. In reality we can have combinations.

B: Data for calculations
We have to find moisture transfer coefficients and boundary conditions. The difficulty is in both cases to select the correct data.

C: Uncertainty in the results
When the calculation has been made we have to look at the results and compare with measured values. Some parameters must in many cases be changed to give a better fit.

D: Risk analysis
After the calculation we have to decide if the results can give moisture damages. In most cases is it not possible to give exact answers. Use of risk analysis can help us.

2. Status in moisture calculations before 1970

Most calculations had to be made by hand, so the models had to be simple. Diffusion of water vapour could be calculated by hand with the flow defined as the difference between indoor and outdoor moisture concentration divided by the total moisture resistance in the construction. The moisture flow must in case of condensation be calculated on each side of the condensation zone. The calculation can be done by hand on a sheet of paper with columns for the data and results, see figure 1. The calculation method is usually called the Glaser method.

layer	thick	lambda	R-resis.	del_t	temp.	sat-conc	diff-num	Z-resis.	del-c	cor conc	trans
	m	W/mK	m2K/W	C	C	kg/m3	m2/s	s/m	kg/m3	kg/m3	kg/m2s
					-3.4	0.004				2.88E-03	
Outdoor			0.04	0.5							
					-2.9	0.004				2.88E-03	
Brick	0.19	0.55	0.35	4.7			2.40E-06	79167	0.004		3.37E-08
					1.9	0.006				5.55E-03	
Plaster	0.005	0.8	0.01	0.1			3.00E-06	1667	0.000		3.37E-08
					2.0	0.006				5.61E-03	
Min.wool	0.05	0.045	1.11	15.2			2.00E-06	2500	0.000		2.31E-07
					17.2	0.015				6.18E-03	
Gypsum	0.013	0.18	0.07	1.0				3000	0.000		2.31E-07
					18.2	0.016				6.88E-03	
Indoor			0.13	1.8							
					20.0	0.017				6.88E-03	
		Sum	1.71	23.4				86333			

Figure 1. Example of Glaser calculation

Using the Glaser-method is easy, but it gives a lot of work if we change a parameter for instance the outdoor temperature. And the problem is always under which climatic conditions can we accept condensation.

3. Computer calculations from 1970

There were central computer centers at the universities so that more complicated models could be used. This could for instance be the model in (1):

$$\frac{dw}{dt} = \frac{d}{dx}\left[D_V * \frac{dc}{dx} + D_W * \frac{dw}{dx}\right]$$

To solve the equation we need to know the sorption isotherm, the vapour and water diffusivity in dependence of the moisture content. The vapour conductivity were at that time based on measurement or tables found in EICHLER (1964), KRISCHER (1963), CAMMERER (1962) and SEIFFERT (1967). It is a serious problem that we still, in 1991, use some of these data in our moisture calculations.
The moisture calculation programs were written in FORTRAN or ALGOL and typically made by the researcher. These programs

were not very easy to change and the results were in many cases given as page after page with numbers. They had later to be drawn by hand to curves. The programs could only be used at the university as they were not very user-friendly and the engineering firms did not have the same computer types.
Figure 2 gives an example of calculated moisture content in a massive roof of cellular concrete. Cellular concrete is the best research material for moisture measurements and calculations.

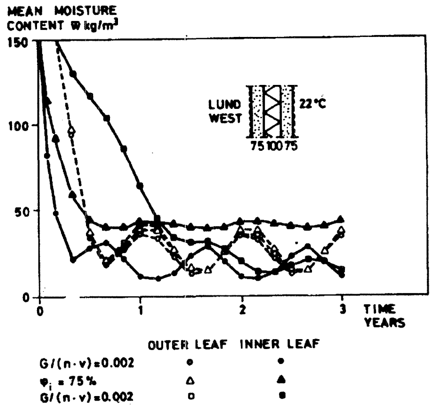


Figure 2. Moisture in cellular concrete roof from (1)

4. Use of the computer in 1990

Now the use of computers has changed dramatically. Today we have a PC (personal computer) on our desk, which has more capacity than the central systems of the 70'ies. The PC can be in the size of a A4-book with a weight of 2 kg and the price is low. So now engineering firms will have many computers, and it is possible to make the calculations locally.
So all new engineers has to know the computer. the most important program to learn is in my opinion the spreadsheet - as Lotus 1-2-3 , Symphony, Excel or other types. These spreadsheets can be used for nearly all the hand calculation methods in building physics - including the Glaser method as in figure 1. The advantage of using a spreadsheet is that you have included the possibility of making drawings of the results. Figure 3 is an example from the Norwegian Building Research Institute (2) of the concentration in dependence of the moisture resistance. And when you use formulas for

calculating the moisture concentration, it is very easy to change some parameter and see the results as numbers or as drawings.

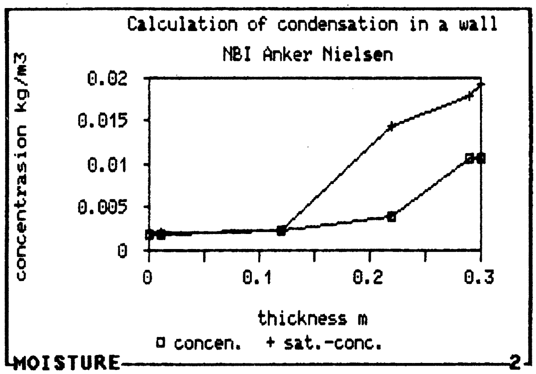


Figure 3 Drawing from spreadsheet from (2).

We have also got a new generation of moisture calculation programs, which are much easier to use. These programs can be used on all personal computers. As an example the MATCH-program (3) and (4) from the thermal insulation laboratory in Denmark. This program can be used by the engineering firms with selected climatic data and moisture transfer coefficients. Figure 4 gives an example of the results. The final version uses colour graphic on the PC for a better presentation and it is easy to change the construction or the necessary material data or boundary conditions. So now the engineering firms can make the moisture calculations for practical cases.

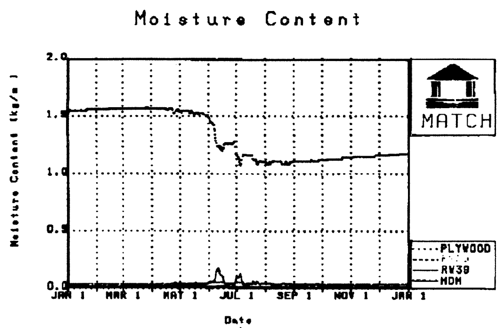


Figure 4 MATCH results from (4).

5. The problems today

Practical problems with moisture calculations are:

A: Boundary conditions
We need information of indoor and outdoor climate and surface resistance. If we want to compare measurements with calculations, will we typically find that we have to make some assumptions about the boundary conditions.

B: Initial moisture content in materials
If we calculate for a real case we do not always know the initial moisture content in the materials. The initial moisture can for instance come from rain during the building period. And that is not well defined.

C: Moisture transport coefficients and sorption curves
To make our moisture calculation we need information of the material. It is a great problem that we have no systematic measurements of these parameters. We will in many cases still use some old value from 1960. Some laboratories make measurements, but they are not always free to use - as the producers paid for the measurements. And the results can differ from laboratory to laboratory depending on variations in the material and the measuring methods.

D: Air flow - moisture convection
The moisture flow by moist air convection is in many constructions more important, than diffusion or capillary flow. But we have to guess the air flow and where the cracks are. This is a very serious problem for our moisture calculations as most constructions contains layers of air permeable materials like mineral wool.

E: Calculations in 2- or 3-dimensions
In some cases will we need moisture calculations in 2- or 3-dimension. Some cases can be solved in 2-dimensions, but we need more computer power. The calculations are too time consuming. The results are more uncertain than the 1-dimensional cases as we have not solved problem A, B and C.

6. Comparison between measurements and calculations

In spite of all these problems it is still possible to get a good agreement between measurements and calculations. Figure 5 gives the construction in a test roof in Denmark. Figure 6 gives a comparison between the measured moisture contents and the calculated for 2 roofs described in (4). It is seen that it has been necessary to make a change in the moisture resistance to get good agreement. This is often done as we for instance do not know the variations in the moisture parameters for the material.

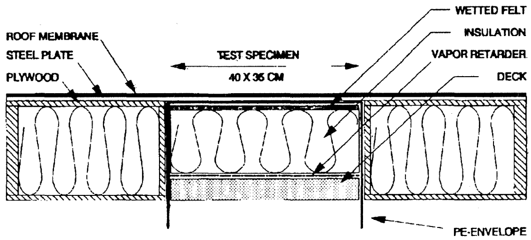


Figure 5. Test roof in Denmark from (4).

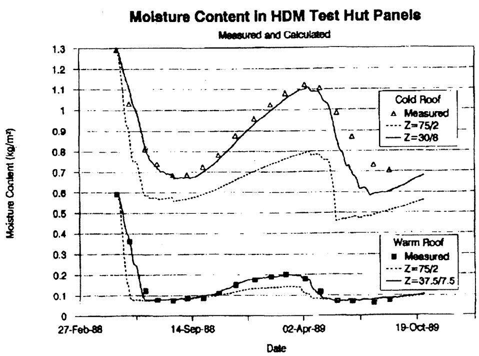


Figure 6. Measured and calculated moisture content in a cold and warm deck roof specimen from field tests. The calculations were performed with ideal as well as fitted vapour resistance (dry/wet) for the Hygro Diode. From (4).

The influence of variations in material parameters is investigated in a project from Lund: Verification of calculation methods for moisture transport in porous building materials (5).
Measurement were done fore different materials and 5 samples were used fore each experiment. Then it was possible to find the variations in one material. Figure 7 gives some results

from 3 cases with cellular concrete. In one of the experiments is observed large variation in moisture content. In the report is also found comparisons between calculations and measurements. To get good agreement, some parameters as sorption curve and moisture diffusivity, were changed.

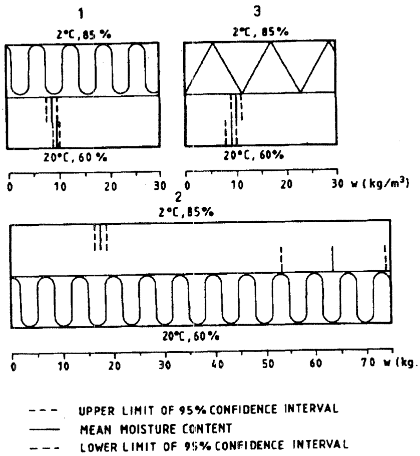


Figure 7. Measured moisture content after 34 days for experiments 1 to 3 with cellular concrete and mineral wool.

By using statistical methods is it possible to shown, that the uncertainty in climate and materials parameters can give a large scatter of the results. In (6) is described the use of random numbers for Monte-Carlo simulations. Figure 8 shows a calculation of the moisture accumulation in a brick wall in dependence of the difference in indoor and outdoor concentration. There is good correlation for this parameter, but others show no correlation. The statistical method can help us evaluate the risk in different constructions (6), (7) and (11).

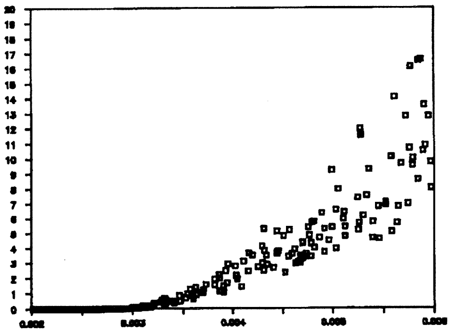


Figure 8. Simulated condensation in kg/m2 in an insulated brick wall in dependence of the indoor moisture increase in kg/m3. From (6).

But the real problems come when we compare measurements in cases where air-flow has large influence. An example of the problems is found in a thesis from Lund (8).

7. Practical problems

Today we can make many calculations, but what is the problem for the practical engineer? In a paper from L.E.Nevander at the CIB W40-meeting in Lund (9), we find the following statement:

The practical engineer is recommended to consider moisture aspects in the following order to avoid damages:

A: Driving rain on the walls and "ordinary" rain on roofs

B: Condensation due to transfer of water vapour with air exfiltration ("moisture convection"). The ventilation system, air humidification, air pressure conditions and air tightness should be considered.

C: Possibilities of evaporation of the initial moisture content.

D: Water vapour diffusion in structures surrounding cold store rooms.

This list is still important today. Note that the vapour diffusion is the least important part and only in cold store rooms. Some comments:

A: That driving rain and normal rain can give much water is well known, but it is almost impossible to calculate the water flow. Normally we assume that the roof is watertight, and the wall has a 2-step tightening. Moisture dimensioning in this case is to look at the details of the drawings and later control of the workmanship.

B: That moisture convection is important is well known from many moisture damage cases, where the construction is not airtight. This is again a case where knowledge of how to make the details is very important. The problems must be solved in the drawing and by control of the workmanship. Calculations of moisture convection can be done, but the problem is that we do not know the cracks and the pressure difference. However by using statistics it should be possible to estimate the moisture convection.

C: The initial moisture content in concrete constructions has to dry out before we put a vapour tight layer as a covering on the surface. Mineral wool with high moisture content from rain in the building period must dry out without damage in for instance wooden parts. It is possible to use moisture models to predict the drying time in these cases, but the initial moisture content is not always known.

D: One of the cases, where we can get serious moisture damages if we have no vapour barrier ,is with cold storage rooms. This can be calculated, but if we also have moisture convection from non air tight layers, we will have problems.

These four points from 1971 should let us remember, that the most important part is to use the right constructions based on experience. Moreover we must look at all connections where there is risk of cracks and air flows. And not the least, we must look at ways to improve quality control in the building period.

8. Conclusions

From the description it would seem like it is very difficult to build without moisture problems. We know from many years experience that we can build good constructions. But sometimes we will get moisture problems. Usually we can later explain what went wrong. Could we have prevented the damage without using to much time and money?

I think the problem consist of 2 elements :

1) **Calculation of the moisture transfer in the construction.** This must be done with our best knowledge of climate and material parameters. The calculated moisture content must be compared with maximal acceptable moisture content.

2) **Evaluation of risk for moisture problems.** This must be based on the detailed drawings of the construction and an estimate of the quality control of the workmanship. This is usually never given as a numerical value - but as an information that one solution is better than another. In the future it can be given as computer based information (10).

The first part can give us numerical information on how much diffusion and/or moisture convection we will get in different cases. To make a risk estimate, this information must be combined with information on how often different cases occur. This must be combined with the evaluation from the second part, which must be based on statistics and information on typical variations in workmanship.

We can continue to make better calculation programs for cases we can solve, but then we cannot predict the risk a certain construction has. Building a knowledge based computer program for moisture design can be done. In Narvik we will start with roof constructions. Some of the knowledge based programs has typically been made to find a single optimum solution. That is not interesting in moisture design - there are many types of constructions. The program should help us to find information on parts of the construction, that has high risk. This could for instance be - a vapour barrier with open joints (risk of moisture convection). If these parts are modified, then the risk will be reduced. The construction must also be acceptable in price, appearance, thermal insulation, statics and so on.

9. References

(1) P.I. Sandberg, Moisture balance in building elements exposed to natural climatic condition, Dr. Thesis, Division of building technology, report 43, Lund Institute of technology, Sweden 1973

(2) A. Nielsen, Use of personal computers for moisture calculations, Symposium of Building Physics in Lund 1987 (page 182-186), BFR D13:1988

(3) C.R.Petersen, Transient calculation of moisture migration using a simplified description of hysteresis in

the sorption isotherms, Building Physics in the Nordic Countries, Trondheim 1990, page 247-252, Tapir, Trondheim 1990

(4) C.R.Petersen, Combined heat and moisture transfer in building constructions, Ph.D. Thesis, Thermal Insulation laboratory, Technical university of Denmark, 1990

(5) A-C.Andersson, Verification of calculation methods for moisture transport in porous materials, Swedish council for building research, D6:1985

(8) L-E. Harderup, Concrete slab on the ground and moisture control, Verification of some methods to improve the moisture conditions in the foundation, Department of building physics, Report TVBH-1005, University of Lund, Sweden 1991

(9) L.E.Nevander, Note on moisture problems from CIB W40-meeting in Lund 1971

(10) A.Nielsen, Building Physics and information technology, Building Physics in the Nordic Countries, Trondheim 1990, page 13-19, Tapir, Trondheim 1990

(11) L.E.Nevander and B. Elmarsson, Moisture design of wood constructions, Risk analysis, (in Swedish) BFR R38, 1991

(7) A.Nielsen, Condensation in a brick wall estimated with statistical methods, Symposium of Building Physics in Lund 1987 (page 177-181), BFR D13:1988

(6) A.Nielsen, Moisture dimensionering with statistics, (in Norwegian) BFR R89,1987

Hugo Hens
KU- Leuven, Lab. of Building Physics
Belgium

CIB W40, HEAT AND MOISTURE TRANSFER IN BUILDINGS YESTERDAY, TO DAY, TO MORROW

PREFACE

The title may suggest a hughe epos, sketching the unbelievable history of a working group within CIB, called **W40, Heat and Mass Transfer in Buildings**. This, it is not. Archives in fact were too scarce to accomplish such a challenge. Therefore, we restricted ourselves to a short historical picture and tried to elucidate and comment part of the 'Practice'-discussion in the group and the way the latent tensions with the central management of CIB were handled.

HISTORY

When the group really started is not clear. In a short 'Note on CIB W40'[1], A.W Pratt claimed 1951, when in Great Britain the 'First International Congress on Building Research' was held, as the early begin of an embryo W40. Indeed, soon afterwards, a first meeting of those interested in thermal problems was organised at Den Haag, The Netherlands. Their research interest quickly crystallised as 'Heat and Moisture Transfer through Porous Materials and Structures'. Other meetings, a.o. in Darmstadt, Germany [2] followed. Famous names in those days were: O. Krischer, J.S. Cammerer, Van der Held.. In 1965, a first separate symposium, dealing with 'Moisture in Buildings' took place in Helsinki, Finland. During that symposium, the interstitial condensation syndrome (= IC-syndrome) dominated the discussions.

1969 saw the official start of W40, when a CIB working group under that name met for the first time in Berlin, Germany, under the co-ordinatorship of B.H.Vos. One of the founding fathers was a swedish professor: Lars Erik Nevander. 12 papers were on the list for presentation [3], most of them of a rather general character. After Berlin, an impressive activity level was demonstrated, with meetings in Lund (1971, 16 papers), Holzkirchen (1972, 29 papers) and Birmingham (1973, 11 papers). 1974 brought a week of reflection on the state of the art with the 'CIB/RILEM Second Symposium on Moisture Problems in Buildings'[4]. Points of interest during that symposium were: origins of moisture in buildings, moisture transfer, influence of moisture on human comfort, influence of moisture on the properties and behaviour of materials, measurement of the moisture content in laboratory and in situ. The symposium was a succes, with 63 papers of high quality submitted for presentation and a positive evaluation by the participants afterwards. Nevertheless, some disillusionment was felt by the members of W40 as no confrontation between research results and practice came out [5]. This caused a slight unease in the group.

After the symposium, the activity level slowed down, with two meetings no longer every year but only each two years: Washington, USA, 1976 (22 papers) and Trondheim, Norway, 1978 (14 papers). The seventhies ended in recession, with three years of no activity until the meeting at Horsholm, Denmark, 1981. Only 11 papers were presented there and the latent discussions the way the group should go on culminated in a provocative paper by A.Pratt. The conclusion after a broad confrontation of opinions was not really revolutionary: W40 still has sense if the working meetings could be more topic and practice oriented. So, idea's on practice topics for the next meeting in Leuven, Belgium, were collected the year after by the coordinator. L.E. Nevander did the following proposal [6]:

1. Exterior surface coefficients of heat transfer h_e;
2. Critical review of calculation methods for internal condensation due to water vapour;
3. Initial moisture content and its drying out;
4. Influence of driving rain on the heat transmission through exterior walls.

The choice of the 4 topics demonstrates one of his major concerns: the need to shape Building Physics as an applied science, a basic design tool for the engineer in preventing and solving problems.

Remarkable fact: the deep of 1981 in the W40 work coincided with the peak in the by purely economical constraints dictated energy research of the early eighties, as an answer to the second energy crisis of 1979.

The Leuven meeting in 1983 saw a change in co-ordinatorship: B.H.Vos resigned and the author of this historical overview took over. At Leuven, 18 papers were presented, with a net shift towards more practice linked problems and a growing inpact of computer modelling[7]. Since, four working meetings happened on bi-annual basis: Holzkirchen 1985 (26 papers)[8], Borås 1987 (29 papers)[9], Victoria 1989 (32 papers)[10] and Lund 1991 (35 papers). As the increasing number of papers show, they were all succesfull, with the attendees list reaching 40 people and more. In Holzkirchen, new terms of reference were adopted, changing the name of the group from the very physical 'Heat and Moisture Transfer in Porous Materials and Structures', into the more direct 'Heat and Moisture Transfer in buildings' and explicitely mentioning in the objectives: *to apply the acquired knowledge in design, execution and maintenance of buildings*. Since the Borås meeting all papers are published in a book of proceedings. The principle of a 'main practice topic pro meeting' however failed. It was abandoned before Victoria, declaring this working meeting open again for all papers within the terms of reference. In the eighties, also the walk over of computer modelling in the field of building physics became very pronounced, with a shift from a users-unfriendly research software to very powerfull, users-friendly, commercially available packages [11].

Remarkable fact: the renewed interest in the W40 work coincided with the decline in the strictly economically driven energy savings research.

As a result of that evolution, in 1987-1989, not W40 but W67, the Energy Conservation Working Group, came in trouble. A good initiative therefore was the organisation of a third symposium, now called 'Energy, Moisture, Climate in Buildings' in Rotterdam, september 1990 [12]. The initiative came from W67, but was backed with enthousiasm by W40 and W77 (Indoor Climate). This symposium mirrored a major challenge for the future: the integration of all aspects of Building Physics in one overall consulting tool for the design engineer with as major objective, to realise a better, performance based building quality.

DISCUSSIONS

As a red line trough the life of W40 runs the discussion on objectives. The group started as a club of researchers. The papers of the Berlin meeting reflect that in a very clear way: some concern 'Research on..', others discuss measuring results or theories but no paper talks about 'Practice'. Also at the Lund, Holzkirchen and Birmingham meeting most papers concentrated on physics, no direct links with design constraints nor performance formulations being found in the titles. However, some unease grew.
During the second symposium in Rotterdam, 1984, B.H.Vos stated in his inauguration speech [13]:

'Ladies and gentlemen, we can distinguish two kinds of science: first of 'all I should like to mention applied, i.e. the science that can be used 'for solving problems in practice. I think most of the work we all do is 'part of this applied science. Then there is pure science. This science 'can be considered as "hoby science". It satisfies our hunger for know- 'ledge and our curiosity. If we consider it as our task to contribute to 'better building, I think we have to increase our knowledge in the field 'of applied science. This means we should not enter into the field of 'pure science. We must not loss our time on our hobbies.

'This should not mean of course that we should not get down to the foun- 'dations of the problems. On the contrary; all too often, it has become 'clear that not walking this way, we were not able to find a solution of 'an important practical problem. In some cases the solutions we found 'turned out to be incomplete. I think, many of us, more than once, have 'found themselves in a situation of great disappointment. Our attack to 'the problem has been too direct. In retrospect, time and money were 'wasted.'

This words perfectly reflect the tension, the question about 'What are our objectives?'. Perhaps, B.H.Vos states it a bit too sharp. Classifying pure

science as 'Hobby Science' is exaggerated. However, building physics is no pure science: we do not question the paradigms and empirical laws of physics, as pure science do, but <u>use</u> them, i.e. characteristic for applied science. That does not mean there is no fundamental applied research. Newton's second law of motion for example is a clear and straightforward one. Fluid flow and convection is studied using it. In spite of, we end with a chaotic system, called turbulent flow, where each flow particle obeys the law, but all particles together behave in an unpredictable way. Opposed to that fundamental applied science, one has direct application, problem solving..etc. This we call 'Practice'. Since 1974, the feeling in W40 multiplied that doing fundamental applied research is great but, if not translated into practice, without objective. And, as the problems encountered in buildings were in most cases a violation of the elementary principles of Building Physics, the opinion gained ground that W40 should concentrate on 'Practice' rather than on 'Research'. This led to the crisis of 1981, as the survival of the group came under discussion.
At the longer end, that discussion has not been solved by effectively turning the group into practice but by accepting realities we cannot deny. W40 is a group of researchers, interested in fundamental applied research. Practice problems are welcomed but will never be the ultimate and only objective of the group. More, handling practice on an international forum is also very difficult. Differences in building tradition, climate, culture and habits in fact complicate all exchanges of 'Practice experiences' or 'Performance rationales'. After all, real practice lays in the consulting, designing and controlling activities of some members of the group or of their institutes, tasks an international group never can concentrate on! However, it's true that the combination of fundamental applied research and practice gives these excellent engineers, Prof L. E. Nevander stands for.

TENSIONS WITH THE MANAGEMENT

The central management core of CIB dreams of a hughe, professional organisation with a direct impact on building practice all over the world. Each new president thus starts with planning a reorganisation of the CIB work. The one calls it a self examination, the other a reformulation of objectives and means. Each time again, greater expectations are placed on the

output of working groups, output being defined as common reports, publications on a prestandardisation level, codes of practice..etc.
Reality however is less prosaic: the working groups have no other resources than the enthousiasm of their full members. They are working thanks to the goodwill of the labs and organisations involved. Therefore, talking about reports, prestandardisation research a.o. remains a dream, because of NO MONEY being avaiable to pay common CIB-work.
W40 published a list with symbols and tried once a project [14]. A common publication on flat roofs should be made. After 4 years the project was withdrown because of no money, too much national pecularities in flat roof construction, no real interest of the group.. Since, the working group has allways defended the 'what is possible' point of view: forget realising more than bringing people together to present and discuss research work within the terms of reference. This is allready a fruitful task: it gives new inspiration, allows critics on each others work and represents in an indirect way an important impetus to the way Building Physics is developing. But above all, a forum is created for younger researchers to get feedback on their work.
I believe W40 has been succesfull with that policy and should go on in the same way, despite all reorganisation blue prints of new presidents.. One of the things my predecessor B.H. Vos said when I took over was: 'You will get letters from the president and other CIB central managers, do not read them and never answer'. I believe B.H. Vos was not the only one who stood for that conviction. I felt the same attitude with all former members of W40. An anecdote illustrates it: searching in the official memberlist, I found out that Lund Tekniska Högskolan, Department of Building Technology, the department where L.E. Nevander was working, is no official member of CIB. Despite, they are very active in W40. Perhaps that non conformist way of functioning explains why W40 did so well in the past and will do well in the future.

THE FUTURE

Here, I can be very short: we must go on the way we did, searching for a still better mix of research and practice, keeping an open mind for new developments and organising high level working meetings, where researchers like to come and have the opportunity to present and defend their work. W40 must in fact remain a forum for researchers and engineers with as common interest: Heat and Moisture Transfer in Buildings, in its broadest sense.

REFERENCES

1. Pratt A.W., A note on W40, CIB W40 working meeting, Horsholm, 1981
2. Personal communication of A. Tveit
3. Nevander L.E., CIB W40 bibliography, CIB W40 working meeting, Trondheim, 1978
4. CIB/RILEM Second International Symposium on Moisture Problems in Buildings, Proceedings, 1974
5. Minutes of the CIB Working Group W40 meeting, Rotterdam, 14/9/1974.
6. Letter of L.E.Nevander for E. Tammes, 29/1/1989.
7. Minutes and proceedings of the CIB Working Group W40 meetings at Leuven (1983)
8. Minutes and proceedings of the CIB Working Group W40 meetings at Holzkirchen (1985)
9. Minutes and proceedings of the CIB Working Group W40 meetings at Borås (1987)
10. Minutes and proceedings of the CIB Working Group W40 meetings at Victoria (1989)
11. See Computer Programmes such as 'Kobru', 'Heat 2', 'Match'..
12. CIB W67 International Symposium on Moisture, Energy and Climate in Buildings, Proceedings, 1990
13. Vos B.H., Introduction to Second International Symposium on Moisture Problems in Buildings, CIB/RILEM Second International Symposium on Moisture Problems in Buildings, Proceedings, 1974
14. See the agenda for the Washington Meeting, 1976, where as first point a publication on flat roofs is mentioned (letter 75-B-1180/BHV/HB to the members of CIB W40), 1975. In 1977, a letter was mailed asking all members of W40 information on boundary conditions and a description of 2 or 3 different types of roofs. At the Trondheim meeting in 1978, the flat roof project was cancelled, because of being an impossible task.

Mark T. Bomberg
National Research Council of Canada, Ottawa
Canada

MOISTURE RESEARCH IN NORTH AMERICA

M. T. Bomberg (editor), National Research Council of Canada, Ottawa, Ont., with cooperation of: D. M. Burch, National Institute of Standards and Technology, Gaithersburg, Md., J.E. Christian, Oak Ridge National Laboratory, Oak Ridge, Tn., P. Fairey, Florida Solar Energy Center, Cape Canaveral, Fl., T. Forest, Alberta Home Heating Research Facility, Edmonton, Alta., T.H. Kuehn, University of Minnesota, Minneapolis, Mn., M.K. Kumaran, NRCC, Ottawa, Ont., D. Onysko, Forintek Canada Corp., Ottawa, Ont., A. TenWolde , Forest Product Laboratory, Madison, Wi., W.C. Thomas, Virginia Polytechnic Institute and State University, Blacksburg, Va., J. Timusk, University of Toronto, G.A. Tsongas, Portland State University, Portland, Or., W. Tobiasson, Cold Regions Research and Engineering Laboratory, Hanover, NH., and G. Wilson, Ottawa, Ont.

INTRODUCTION

Seen from the perspective of someone who 25 years ago started working on fundamentals of moisture transport in building materials and 15 years ago moved to other research concerns, the invitation to review one's old field of research was a pleasure, doubled, as this symposium is to celebrate my academic mentor, prof. Lars Erik Nevander.

Moisture research in North America is a dynamic, but extremely fragmented field. To relate this fragmentation to a more"product competitive" American environment may not be enough. This fragmentation is also caused by a low frequency of moisture damage, lower than it appears to be shown in the European records[1] . Will the fraction of moisture damage increase when the cost of energy becomes a factor in the North American housing market?

Lstiburek[2] reviews the historic changes - from the old, leaky and poorly insulated homes with an oil furnace and central air heating system to a modern, tight and often electrically heated house - in terms of the drying potential. Moisture in the envelope, whether it comes from an incidental rain leakage or the indoor air, must be allowed to dry out. The probability of getting moisture into the building envelope did not change much with time, yet, all the changes in the construction pattern dramatically reduced the drying potential of the building envelope.

---

[1] Gertis K, "Building physics : trends and future tasks for civil engineers and architects", Int. Ass. for Bridge and Structural Eng., IABS Periodica, 3, August 1982

[2] Lsiburek J, "Historical perspective on North American wood frame construction", Info & Technology transfer, J. Thermal Insulation, October 1991

While one may not agree with it, nevertheless, the objective of moisture research in North America is often defined[3] as development of means to assess houses prior to its energy upgrading or energy retrofits, means to ensure that moisture problems would not occur in effect of the "improvements". As moisture research in North America is mostly related to the energy conservation, issues of the architectural design, system performance or durability of the materials are often addressed in a marginal way. The absence of coordinated research on the material and system moisture performance aspects is one of many barriers slowing introduction of new technology or new materials to already a very conservative sector of economy. Therefore, some attempts are made to sponsor national programs by such institutions as the Oak Ridge National Laboratory (ORNL) and the National Institute for Standards and Technology (NIST) in the United States or by the Canada Housing and Mortgage Corporation (CMHC) and National Research Council of Canada.

American Society for Testing and Materials (ASTM) sponsors also a moisture manual. This manual is to bring together in one volume, as a desk top reference the information on applicable technology relating to moisture problems in buildings, their diagnosis, prevention and rehabilitation; to synthesize the information for the design practice and to identify the needs for more effective implementation of moisture control strategies in the future.

The implementation of moisture research is far from being satisfactory. One may speculate that the fragmentation of this research field makes difficult if not impossible to address more complex issues of system evaluation. Thus, a part of the academic community questions the efficiency of the current moisture research. To enhance this discussion a review of both the past and the future of the moisture research in North America is needed. To this end, this paper in two separate parts (one for Canada, one for the US) presents research profile and the list of published projects (bibliography) for each of the leading research centers. While the first author acted as the editor, all contributors to this paper are acknowledged.

SCOPE OF THE MOISTURE RESEARCH

Figure 1 shows the two dimensions of the moisture control in buildings. Horizontally, from left to right, one may see the practice, science and research, i.e. the knowledge axis. The science lies between the practice and the research. This fact implies that the practice follows the advances of the science and that research leads the development of the science and attempts to fill the gaps existing on the frontiers of science. However, when filling these gaps and extending the limits of knowledge, one must also take into consideration the manner in which the new knowledge can best be transferred to the construction practice. This process is marked by horizontal arrows leading from research to practice.

---

[3] Johnson A.W., "Do we have a moisture problem", Moisture Control in Buildings, Building Thermal Envelope Coordinating Council, Washington, D.C., Sept 1984,

Vertically, from top to bottom, are the materials, components and systems, i.e. the performance hierarchy axis. On the level of materials the practice comprises the material specifications and the standard test methods defined by various standard organizations e.g., American Society for Testing and Materials (ASTM). On the research side are materials and products and their response to moisture (moisture effects).

On the level of building elements and components, main level for analysis of the building envelope, the practice comprises of building codes and design tools, guidelines and typical architectural details. The research on building elements and components deals with the evaluation of their field performance. This is rather a complex question involving climate and service conditions, design, building site and occupancy factors and its complexity often stipulate use of the computerized models of component performance.

Finally, on level 3 (systems), case studies and guidelines for the space rehabilitation are on the practical side while the commissioning tests and the computerized system models are on the research side.

Figure 1 presents the scope of moisture control in materials, components and systems, and may, therefore, be used as a background for presentation on the current research activities. But the first things, first. Let us first review the field of moisture research.

PART 1: MOISTURE RESEARCH IN CANADA

1. THE UNIVERSITY OF TORONTO

What we have been engaged in could be classified as a combination of RDD and I, research, development, demonstration and implementation. We should, perhaps, add the letter E to the above collection, denoting education, which is our primary responsibility, but then it is already dealt with as a part of implementation.

Experience has taught us that the building industry, at least in Canada, is unaccustomed to accepting change, and reluctant to support research which is likely to lead to change. There are, of course, always exceptions and to them we owe a debt of gratitude. Experience has also taught us that it is not enough to do the basic research and publish it in a scientific journal, and even to do the development work and demonstrate the developed product to the building community; we often have to participate directly in putting the concept into practice.

To make all this happen we have had to become a part of the building industry, initiating change from within and at the same time assisting it to solve some of its problems; we have had to become builders and we have had to become building code and specification writers. We have, in effect, assumed many of the characteristics of a teaching and research hospital.

This approach is reflected in our publications: they range from the presentation of research findings. the description of demonstration projects to a response to the education needs of a specific segment of the building industry.

While our building science laboratory is adequately equipped, we have largely used it to back up the research we carry out on actual buildings. Here we have been particularly fortunate in being able to participate in major Canada-wide moisture investigations; a laboratory where a number of extreme climate conditions are found.

The selected papers and reports are listed here in more or less chronological order of when the projects were conceived. Execution of the work could often have to wait for suitable graduate students and research funding.

An important turning point in my professional career was the year spent at the Royal Institute of Technology with Ingemar Hoglund and Arne Elmroth. Their influence is clearly evident in much of our work, and with it a circle has been closed in that before that, Professor Hoglund had spent a year at the Division of Building Research of the National Research Council of Canada with the late Dr. Neil B. Hutcheon.

For a while it looked that we would not be able to get out of the basement work which was launched on work done at the Royal Institute of Technology. The report: *Study of Scandinavian Foundation Insulation Practices*, published by the Canadian Home Builders Association resulted in a major cross-Canada research and development project involving builders, insulation manufacturers, regulatory authorities and ourselves.

This was followed by a study of the insulating of existing basements and a 170-page how-to report titled *Insulation retrofit of Masonry Basement*, J. Timusk, 1981, on behalf of the Ontario Ministry of Housing. Written in lay language for home owners, an attempt was nevertheless made to provide the background physics necessary in the decision making process. Neil Hutcheon had taught us that it was dangerous to give solutions to problems without first providing the required understanding. Otherwise there is a danger that the solution would be applied to another problem which was not quite the same as that for which solution was intended. Central to this report is the control of liquid water and moisture.

The one question which was repeatedly raised was the potential wetting of glass fibre insulating board for external insulation of basement walls. The paper: *Mechanism of Drainage and Capillary Rise in Glass Fibre Insulation* by J. Timusk and L.M. Tenede describes our work concerning this issue. It was published in the Journal of Thermal insulation, Volume 11 - April 1988, pp. 231-241. Here it was shown that as long as the predominant fibre orientation was in the plane of the insulating board, water introduced into a vertically positioned board would remain in the plane it was introduced into, that there was no measurable capillary wicking in the direction normal to the board and that if the glass fibre diameter distribution and packing density were know, the Young and LaPlace equation could be used to predict capillary rise parallel to the insulating board.

In 1982 an opportunity arose to participate in a major cross-Canada study of *Moisture Induced Problems in NHA Housing*. This study provided a unique opportunity to gain insight into many deficiencies in building practice. The extreme moisture loading imposed on most of these houses, mainly due to flueless electric heating and a consequent lack of ventilation, made it possible to gain insight into deficiencies in the way we build wood frame houses. See the *Literature Review and Research* part of this study, J. Timusk, Canada Mortgage and Housing Corporation report, Cat No. NH20-172-1983-2E, 62 pp.

The above study raised more questions than it answered, and lead to number of studies by ourselves.

For example, the appearance of mould and mildew on room-side surfaces of exterior corners could not be explained without, in addition to all the know processed, speculating that wind pressure was causing a flow of air to take a short circuit around the corner by entering the wall cavity via flaws in the sheathing. A full scale laboratory study verified that wind could indeed lead to an additional temperature drop of up to 7K beyond that due to all the other effects found in an exterior corner. *The control of Wind Cooling of Wood Frame Building Enclosures*, J. Timusk, A.L. Seskus and N. Ary, proceedings, Sixth Annual International Energy Efficient Building Conference, April 27-29, 1988, Portland, Mine, 11 pp.

In the CMHC study it was also argued that insulating sheathing would significantly improve the performance of walls. The laboratory study on the *Effect of Insulating Sheathing on Heat and Moisture Flow*, J. Timusk and H.B. Doshi, *Canadian Journal of Civil Engineering*, Vol. 13, 1986, pp. 674 to 680, showed that leaving deliberate ventilation slots between extruded polystyrene insulating sheathing boards had little if any adverse effect on the thermal performance of walls, but that the slots did also not reduce the accumulation of moisture in the wall cavity from an interior air leakage source. Glass fibre insulating sheathing boards with an attached vapor permeable spunbonded polyolephin membrane was able to store moisture condensed from interior air during extreme moisture condensed from interior air during extreme moisture conditions while the framing members were kept dry.

In the CMHC study it was further proposed that the air barrier could be located on the cold side of thermal insulation where it is not only easier to install and inspect, but where it will also perform the dual function of preventing wind cooling of wall assemblies. To demonstrate this we had to build a house incorporating the concept. Measurement demonstrated that the house did indeed meet the Canadian low energy housing, the R-2000 program, air tightness requirements of maximum infiltration of 1,5 air changes per hour at 50 Pascals, and this while the vapor permeable and also somewhat air permeable "air barrier" was responsible for some 60% of the infiltration. In effect, we had built a dynamic wall house. *Design, Construction and Performance of a Dynamic Wall House*, J. Timusk, proceedings, the 8the Air Infiltration Center Conference, September 24, 1987, Uberlingen, FRG, 16 pp. From the moisture control perspective the operation of a house under sufficient negative pressure to overcome exfiltration due to wind and stack action, thereby eliminating one of the major causes for moisture damage in wall cavities. It was also shown that construction moisture would be rapidly dried out when ventilation air is drawn through the wall cavity and becomes heated up in the process.

Laboratory and dynamic wall house energy performance studies have now been completed and technical papers concerning this work are currently under preparation.

My overall perspective about moisture work is that too much is done on analysis and modelling, too little on the development of designs which provide a high level of thermal comfort, excellent air quality, are cheap to build, consume little energy and are immune to moisture problems. I think we have come closer to reaching this goal with the dynamic wall house, but that we still have a long , long way to go before such houses become a part of everyday building practice. Implementation is again the most difficult part of the problem.

2. THE ALBERTA HOME HEATING RESEARCH FACILITY

Research activities on moisture problems in residential buildings involves a field monitoring program and modeling. The two areas of current interest are moisture deposition in exterior walls and attics during winter. Field monitoring is underway at Alberta Home Heating Research Facility (AHHRF) which is a test site near Edmonton consisting of six, single storey houses with full basements, arranged in an east-west row. Two of the houses are humidified during winter and moisture deposition in the walls and attic, together with ventilation rates and forced convective air flows through each zone are monitored continuously. The objective of this phase is to collect a large database on convective air flows (dominant moisture transport mechanism) and moisture deposition. Concurrently, model development is underway to predict moisture deposition in walls and attics, with the database used for model validation. The wall model is based on heat and mass transfer across a cavity filled with porous insulation with forced convective air flow in a vertical direction. condensation (or sublimation) occurs on the cold exterior sheathing and the amount and distribution of moisture is predicted by the model. The attic moisture model consists of two sub-models; one is a two zone, indoor-attic air ventilation model based on air flow mass balances in each zone and the other is an existing thermal-moisture balance model which uses the attic ventilation rate and indoor-attic exchange rate as input.

Future work will involve using these models to identify construction details (such as, size and placement of passive roof vents) and ventilation strategies to eliminate or control moisture in houses under the varying winter conditions experienced in Canada. It is planned to field test some of the ideas that have been identified by model calculations at AHHRF during the next few winter seasons.

Bibliography

Moisture Accumulation in a Building Envelope - Phase I Report -T.W. Forest and R.

You, Dep. Mech.Eng. Report #63, University of Alberta, Edmonton Alberta, Nov. 1987.

Moisture Accumulation in a Building Envelope - Phase II Report - 1987-88 Heating Season, T.W. Forest and K. Checkwitch,Report #67, U. of Alberta, Edmonton, 1988.

Moisture Transfer through Walls, T.W. Forest , ASHRAE/DOE/BTECC/CIBSE Conf. Ext. Env. IV, Orlando, Florida, Dec. 1989, pg. 532.

Evaluation of the Performance of Attic Radiant Barriers T.W.Forest, report to Alberta Municipal Affairs, Edmonton, Alberta, June 1990.

Drying of Walls - Prairie Region ,T.W. Forest and I.S. Walker ,Report to Canada Mortgage and Housing, Project Implementation Division, Dec. 1990.

Moisture Accumulation in a Building Envelope - Final Report , T.W. Forest, I.S. Walker and K.Checkwitch, Report #80, U. of Alberta, Edmonton Alberta, April 1991.

Field Study on Attic Ventilation and Moisture, T.W. Forest and I.S. Walker, Proceedings of CANCAM '91, Winnipeg, Manitoba, June 1991. pg. 546.

3. FORINTEK CANADA CORPORATION

3.1 Current work : **Air leakage through joints in exterior panel sheathing as a function of lumber drying**

This is the main study that followed the pilot study on this topic reported in 1989. Twenty four (24) full-sized test walls have been built and tested for air leakage. Two joint configurations are represented as well as shrinkage of wood from the green state and from the 19 percent moisture level. An additional six (6) full-sized walls have been built and tested to study the influence of lumber shrinkage on air leakage around the wall-to-floor connection in platform construction. Various techniques to minimize air leakage through these joints were also assessed. Two reports on this work are in preparation.

Moisture in lumber framing of houses under construction

The levels of moisture built into walls in actual construction have not been studied. Many factors influence this including the climate, possible re-wetting of lumber during construction, the use of S-GRN* of S-DRY** lumber, and the rapidity of construction. This field study, conducted for Canada Mortgage and Housing Corporation, obtained the moisture content of over 6000 wall studs and plates in 515 houses across the country. The moisture content was measured in the lumber just before the installation of insulation and the vapor retarder. The study was aimed at

---

* S-green wood, i.e. surfaced when green is cut to a size, plained and graded but not dried. (Ed)

** S-dry wood, i.e. surfaced when dry, is first dried and then sorted and plained. (Ed) obtaining information on the moisture content of lumber framing for computer modelling of the drying performance of walls, and for studying the factors noted above.

The study confirmed that mostly 38 by 189 mm studs were being used throughout the country for wall construction. The Prairie region builders used predominantly S-DRY lumber while the Atlantic region builders generally used S-GRN lumber. Wall plates generally had higher moisture content than the studs. While the S-DRY lumber was often drier than the 19% moisture content level required in the National Building Code of Canada, a significant percentage of the lumber was above this value and a percentage of the material was over fibre saturation (over 30% moisture content). This was due, in part, to re-wetting, but also it was due to insufficient initial drying and the inclusion of hard-to-dry species. Climatic drying could not always be counted on to produce drying during construction. Drywall problems (nail popping and cracking) were generally experienced by most builders and most were prepared to pay a premium for drier lumber assuming this would reduce shrinkage and resulting distortions. Recommendations were made to study construction techniques to take better advantage of climatic drying. It was also recommended that builders pay greater attention to the moisture in the lumber they use, and that the lumber industry use better quality control on the moisture content of S-DRY lumber.

3.2 Completed work :

Air Tightness of one Type of Hardboard siding, D.M. Onysko and S.K Jones, Contribution to CIB-W40 Meeting, Victoria, B.C., 1989

A test wall was built to assess leakage through joints in hardboard siding. The results show the effect of the nail type, nailing technique and vent holes. Variation in air tightness of joints masked the influence of small vent holes and the influence of air flow direction. When nails are overdrawn, the joints are much tighter. The average leakage found for typical siding joints in this study was about 15 times less than that obtained by others on smaller sample walls.

Air Tightness of Two Walls Sprayed with Polyurethane foam Insulation, D.M. Onysko and S.K. Jones, Contribution to CIB-W40 Meeting, Victoria, B.C., 1989

Can walls with sprayed polyurethane foam maintain their air tightness and energy efficiency over time despite the changing moisture and temperature environment they may be exposed to. Tests showed that the air tightness of the walls was relatively unaffected by the drying of the lumber. There was sufficient bond between the foam insulation and the lumber, and sufficient elasticity in the material, that little change in air tightness occurred beyond the initial high pressure test. Both the polystyrene-sheathed and waferboard-sheathed walls dried at a similar rate after accounting for differences in initial moisture content of the lumber framing. But, the slow rates of drying of high moisture content lumber suggests use of wood dried prior to the foam spraying.

Airtightness of Wall Sheathing as a Function of Lumber Drying, D.M Onysko and

S.K. Jones, proceedings of the ASHRAE/DOE/BTECC/CIBSE Thermal Performance of Exterior Envelopes, IV conference, Orlando FL, 1989

4. Institute for Research in Construction, National Research Council Canada

Hygrothermal behavior of building materials and components.

This project was undertaken with following objectives:

1. to develop experimental and analytical tools to assist researchers to evaluate the hygrothermal behavior, and
2. to develop design guidelines for building envelopes free of moisture related performance problems.

With the above objectives in mind, researchers at IRC have been working in collaboration with a group of researchers from the Technical Research Center of Finland (VTT) for the past three years. The emphasis was specifically on two topics:

1. to develop experimental capabilities to determine moisture transport properties of building materials and
2. to investigate the applicability of a two dimensional computer programme developed at VTT for hygrothermal analysis of residential buildings.

This report briefly presents some results from the research activities.

Experimental Investigations:

IRC has developed a gamma-ray equipment for the determination of moisture distributions in building materials. The materials investigated to date include: eastern white pine, spruce, wood fibre board, gypsum board, phenolic, glass and cellulose fibre insulations.

Transient moisture distributions in test specimens of the above materials were determined at various stages of the transport processes. The duration of the experiment varied from few hours (gypsum) to few weeks (spruce and pine). The data were analyzed for deriving total moisture diffusivity of the building materials. Two different techniques were used in the analysis: Boltzmann transformation and optimization method.

Except for cellulose and glass fibre insulation, the analyses resulted in acceptable sets of values for respective total moisture diffusivities as a function of moisture concentration. To determine the moisture transport characteristics of glass fibre and cellulose insulations a number of other experiments were carried out. These include: drainage, evaporation of fully saturated specimens and moisture movement in the presence of thermal gradient.

The analyses of these data for glass fiber resulted in a consistent set of values for properties such as vapor diffusivity, hydraulic conductivity and suction pressure curve. A report on this will be presented at the W40 meeting in Lund. The development of an experimental procedure for the determination of "thermal moisture diffusivity" is also in progress.

Computer Model Calculations:

The computer model TCCC2D developed at VTT was used in several calculations where typical Canadian residential walls were investigated. In particular the effect of exfiltration indoor air through wall cavities was analyzed. Exposure of the wall to Canadian weather at three different locations, viz. Ottawa, Winnipeg and Vancouver for one year were simulated. These simulations resulted in several interesting pieces of information. The difference in the behavior of the same wall assembly, but in three different locations in Canada indicates the need for different design guidelines for the three regions.

Currently the model is being used for other cases of practical importance.

Bibliography:

Moisture content in protected membrane roof insulations - effect of design features, C.P. Hedlin, ASTM, Special Technical Publication No. 603, 1976

Moisture gains by foam plastic roof insulations under controlled temperature gradients, C.P.Hedlin , J. Cellular Plastics, Vol. 13, No. 5, 1977, pp. 313-319. (NRCC 16317)

Some design characteristics of insulation in flat roofs related to temperature and moisture, C.P. Hedlin, NBS/NRCA Nat. Conf. Roofing Technology, 1979.

Some factors affecting drainage of moisture from wet insulation in flat roofs, C.P. Hedlin, ASTM, STP 779, pp. 28-40. (NRCC 20984)

Effect of moisture on thermal resistance of some insulations in a flat roof under field-type conditions, C.P. Hedlin , ASTM, STP 789, 1983, p. 602-625. (NRCC 22430)

Calculation of thermal conductance based on measurements of heat flow rates in a flat roof using heat flux transducers, C.P.Hedlin, ASTM, STP 885, 1985, p. 184-201. (NRCC 25350)

Seasonal variations in the modes of heat transfer in a moist porous thermal insulation in a flat roof., Hedlin C.P, J. Thermal Insulation, Vol. 11, 1987, p. 54-66. (NRCC 28548)

Heat Transfer in a Wet Porous Thermal Insulation in a Flat Roof, C.P. Hedlin, J. Thermal Insulation, Vol.11, January 1988, p. 165-188. (NRCC 29215).

Calibration of humidity sensors at DBR/NRCC, Saskatoon., C.P. Hedlin and R.G.

Nicholson, Proceedings of the International Symposium on Moisture and Humidity, Washington, D.C., April 15-18, 1985. (NRCC 24731)

Effect of Insulation Joints on Heat Loss through Flat Roofs, C.P. Hedlin , ASHRAE Transactions 1985, Vol. 91, Part 2B, 23-27 June 1985, p. 608-622. (NRCC 27996).

Heat Flow Through a Roof Insulation Having Moisture Contents Between 0 & 1% by Volume, in Summer, C.P. Hedlin, ASHRAE Transactions 1988, Part 2, p. 1579-1594, (NRCC 31111 IRC 1636).

Effect of solar heat on moisture gains in building perimeter insulation beneath a paving-stone walkway, C.P.Hedlin, D.G.Cole, September 1982, 4p., 5 figures, (BRN 193)

Moisture content and dimensional stability measurements of the insulation on a protected membrane roof, C.P. Hedlin , March 1986, 6p. (BRN 246)

Performance of roofing components and systems. Roofs That Work - BSI '89, C.P.Hedlin ,1989, Ottawa Ontario

Laboratory methods for determining moisture absorption of thermal insulations., M.T.Bomberg, I: Review. J. Thermal Insulation, Vol. 6, 1983, p.232-249. (NR 22458)

Laboratory methods for determining moisture absorption of thermal insulations, M.T.Bomberg,and R.Dillon , III. Interlaboratory comparison of water intake of rigid thermal insulations. J. Thermal Insulation, Vol. 8, July 1984, p. 1-16. (NRCC 23774)

Testing Water Vapor Transmission: Unresolved Issues ,M.T.Bomberg, ASTM STP 1039, 1989, p. 157-167. (NRCC 30891 IRC 1615).

Influence of moisture and moisture gradients on heat transfer through porous building materials, M.T. Bomberg and C.J.Shirtliffe, American Society for Testing and Materials, Special Technical Publication No. 660, December 1978, p. 211-233. (NRCC 17138)

Glass fiber as insulation and drainage layer on exterior of basement walls., S.S. Tao , M.T. Bomberg and J.J. Hamilton, ASTM STP 718, 1980, p. 57-76. (NRCC 19317)

Development of thermal insulation performance test methods., M.T. Bomberg, Studies in building physics, 1981, Lund Institute of Technology, Sweden, ASTM Standardization News, December 1982, p. 26-32. (NRCC 21223)

A gamma-spectrometer for determination of density distribution and moisture distribution in building materials., M.K. Kumaran and M. T. Bomberg, Proceedings of the International Symposium on Moisture and Humidity, Washington D.C., April 15-18,1985p.485-490. (NRCC 24693)

A test method to determine air flow resistance of exterior membranes and sheathings, M.T.Bomberg, and M.K. Kumaran,. J.Thermal Insulation, Vol. 9, Jan 1986, p. 224-235.

Measurement of the Rate of Gas Diffusion in Rigid Cellular Plastics., N.V. Schwartz , M.T. Bomberg and M.K. Kumaran , J. Thermal Insulation, Vol.13, 1989, p. 48-61. (NRCC 30906 IRC 1620).

Water Vapor Transmission and Moisture Accumulation in Polyurethane and Polyisocyanurate Foams , N.V. Schwartz , M.T. Bomberg and M.K. Kumaran , ASTM, STP 1039, 1989, p. 63-72. (NRCC 30890 IRC 1614).

Introduction to the System of Moisture Performance Analysis, M.T.Bomberg M.T, C.J. Shirtliffe and H.R. Trechsel , Chapter 5.1 in ASTM Manual on Moisture in Buildings, in preparation

Research needs, M.T. Bomberg and M.K. Kumaran, Chapter 5.2 in ASTM Manual on Moisture in Buildings, in preparation

Heat transport through thermal insulation: An application of the principles of thermodynamics of irreversible processes,M.K. Kumaran and G.G. Stephenson , Am. Soc. Mech. Eng. ASME Paper No. 86-WA/HT-70, 1986, p. 1-4. (NRCC 27451)

Moisture transport through glass-fibre insulation in the presence of a thermal gradient., M.K. Kumaran , J. Thermal Insulation, Vol. 10, April 1987 p. 243-255. (NRCC 28451)

Comparison of simult. heat and moisture transport through glass-fibre and spray-cellulose ins., M.K. Kumaran , J. Thermal Insulation, Vol. 12, 1988 p. 6-16 (NR 29841)

Heat transport through fibrous insulation materials, M.K. Kumaran and D.G. Stephenson, J. Thermal Insulation, Vol.11, April 1988 p. 263-269. (NRCC29639)

Vapor Transport Characteristics of Mineral Fiber Insulation from Heat Flow Meter MEASUREMENTS M.K. Kumaran , ASTM, STP 1039, 1989, p. 19-27. (NRCC 30889).

Methods to Calculate Gas Diffusion Coefficients of Cellular Plastic Insulation from Experimental Data on Gas Absorption, G.P. Mitalas and M.K. Kumaran , J. Thermal Insulation, April 1991, Vol. 14, pp 342-357.

Analysis of simultaneous heat and moisture transport through glass fibre insulation. M.K. Kumaran and G.P. Mitalas, HTD Vol. 78, Book # H00397, 1987 National Heat Transfer Conference, ASME/AICHE, 1987 p.1-6.

Simult. heat and moisture transport through glass fibre ins.: An inves. of the effect of hygroscopicity, G.P. Mitalas & M.K. Kumaran , ASME, 1987, Vol. 4, p. 1-4. (28974)

Experimental invest.igation on simult. heat & moisture transport through thermal insulation, M.K. Kumaran ,Proc. CIB XIth Int Con, France, 1989, Vol 1, p. 458-465.

Moisture Transport Coefficient of Pine from Gamma Ray Absorption Measurements, M.K. Kumaran , G.P. Mitalas , R. Kohonen R. and T. Ojanen ASME - HTD - Vol. 123, Book No. H00526 - 1989,p. 179-183 (NRCC 31637)

Application of gamma-ray spectroscopy for determ. of moisture distribution in insulating mtls., M.K. Kumaran, XXI ICHMT Symp. Ht & Mass Txfr, Dubrovnik, Yugoslavia

Gamma-spectroscopic determination of moisture distribution in medium-density glass fibre insulation, M.K. Kumaran, March 1986, 13p. (BRN 242)

Fundamentals of Moisture Transport and Storage in Building Materials. Kumaran M.K., Mitalas G.P., Bomberg M.T. ASTM Manual on Moisture in Buildings, Chapter 1.1. in preparation

Modelling and Calculating Moisture Transport and Storage in Building Materials and Components. T. Ojanen , R. Kohonen and M.K. Kumaran ,ASTM Handbook on Moisture in Buildings, Chapter 1.2., in preparation

5. CANADA MORTGAGE AND HOUSING CORPORATION

Canada Mortgage and Housing Corporation (CMHC) has supported an extensive moisture related research and knowledge transfer activities over the past 15 years. The work is planned and directed by in-house staff , but is largely carried out by consultants under contract.

Initially, the work was largely driven by reports of moisture problems in Atlantic provinces e.g. buckling of siding materials. A major national survey (see bibliography) concluded that a fraction (about 1 percent) of the Canadian housing stock had moisture related structural damage, while about 10 % had other moisture problems such as window condensation and mould growth on the indoor surfaces. The incidence of these problems was significantly higher in the Atlantic provinces than in other regions of Canada. This was taken to be related to climate conditions, including reduced potential for drying of wall components.

To develop a better understanding of the factors affecting the annual cycle of moisture content in walls, test buildings were constructed in three Atlantic provinces. These incorporated a number of sheathing materials, with and without strapping beneath the siding (see report by Oboe Eng). Observation of very high initial moisture content led to regional and national surveys, the later reported in section 3 of this review.

While Atlantic test buildings indicated relatively slow drying rate of framing components, particularly with low permeance sheathing materials (and mould growth in the cavities), similar test buildings subsequently built in Ontario (Ontario Wall Dry Project, Building Engineering Group, U of Waterloo, CMHC, 1991) and Alberta U (see section2 of this review) indicated much more rapid drying.

To predict moisture content changes in wall components a computer model was developed (1988) and compared with test building measurements. This comparison, while giving encouraging results, led to the conclusion that better material characteristics and a more complex model were needed (1990). A revised model has been assembled, using a finite element approach, and is awaiting verification trials.

The 1982 national survey of moisture problems found that most troubled houses had a high level of indoor relative humidity. Further studies on moisture sources indicated that moisture stored in indoor materials in summer and ground related moisture could become major sources in winter time. A project sponsored by Energy, Mines and Resources Canada used the CMHC results as a starting point in the development of a procedure for use by retrofit industry to assess how much airtightning of house could be carried out before moisture problems were likely to occur (Avoiding Moisture Problems when Retrofitting Canadian Houses to Conserve Energy, Scanada Consultants Ltd and others, EMR, 1988). Another study has provided data on airtightness of recently constructed houses (1989 Survey of the Airtightness of New, Detached, Merchant Builder Houses, CMHC, IRC, EMR Canada, CHBA).

A number of CMHC projects have been directed to requirements for wall design to reduce air leakage, and thus moisture transport by infiltration, and to reduce rain penetration through application of rain screen principles. Tests have been carried out to establish the airtightness of wood frame wall specimens incorporating a range of air barrier systems and construction details and structural requirements for air barriers. Furthermore, concern over long-term stability of polyethylene film, widely used as a vapor and air barrier in wood frame walls in low rise residences, led to series of studies on durability of the polyethylene in service and appropriate changes in the Canadian standards.

A number of parallel studies have been carried out on the performance (including moisture) of high-rise residential constructions employing steel-stud curtain wall systems, and on the development of good construction practices (Exterior Wall Construction in High-Rise Buildings: Brick Veneer on Concrete Masonry or Steel Studs, R.G.Drysdale and G. T. Suter, CMHC, 1991). Field examination of masonry clad, steel-stud wall systems revealed problems with corroding studs, wet walls, and fungal contamination (Field Investigation of Brick Veneer Steel-Stud Wall Systems, Sutter-Keller Ltd, CMHC 1989).

Current studies involve application of recommended construction practices to a major building project , to be followed by monitoring of performance; and determination of the air leakage, air movement and air quality in several multi-storey residential buildings across the country. In one building air tightness is being determined before and after airtightning retrofit. The objective is to establish good construction and retrofit practices for high-rise residential constructions.

Bibliography:

Moisture challenges in Canadian Energy efficient Housing, T.Robinson, CIB Moisture Symposium, Rotterdam, 1990

Ventilation and Airtightness in New Detached Canadian Housing, T.Hamlin, J.Orman, M.Lubun, CMHC,Ottawa, Ont,1990

Moisture Transport in Walls: Canadian Experience, Jim H. White, STP1039, Am. Soc.Testing and Mat., 1989 p. 35-50

Report on Atlantic Canada Wood Framing Moisture Survey, Prepared by the Project Implementation Division, Canada Mortgage and Housing Corporation, Final Report, May 1989

Wood Moisture Monitoring- Halifax, Nova Scotia, Prepared by Oboe Engineering Ltd., for CMHC, May 1988

Field Trials of Test Procedures to Determine Internal Moisture Source Strength, by the BEST Corporation (Balanced Energy Systems Technology Inc., for CMHC, July 1984

Moisture Source Strength: Measurements in selected Canadian Cities, by Appin Ass., Eneraction Resources Inc., Pearson Glanbrook Ass.,Provincial Cons., Scanada Cons., CMHC, 1987

Moisture Induced Problems in NHA Housing: Part 1, Analysis of field Survey Results and Projections of Future Problems, Part 2, Literature Review and Research, Part 3, Applicable Moisture Reduction Techniques for Newfoundland, by Marshall Macklin Monaghan Ltd, Prepared for CMHC, 1983

CMHC/CHBA Joint Task Force on Moisture Problems in Atlantic Canada - Final Report, February 1988

Drying characteristics in timber frame walls of low-rise residential housing - final report, Rowan, Williams, Davis and Irwin Inc., and Scanada Consultants Ltd., for CMHC, April 1988

Comparison of Walldry Predictions with Atlantic Canada Moisture Test Hut Data, Prepared by G.K. Yuill and Associate Limited, Winnipeg, Manitoba, for CMHC, January 1990

Field Monitoring of Cellulose in Walls - Edmonton, Building Envelope Engineering, Calgary, Alberta, for CMHC, January 1990

Testing of Air Barrier Systems for Wood Frame Walls, W.C. Brown, IRC / NRC, for CMHC, April 1987

Testing of Air Barrier Construction Details, Morrison Hersfield LTD, for CMHC, 1991

The Development of Test Procedures and Methods to Evaluate Air Barrier Membranes for masonry Walls, Ortech Int, for CMHC,1990

Structural Requirements for Air Barriers, Morrison Hersfield Ltd, CMHC, 1991

Prairie Moisture Problems: Crawl Space Investigations in Norway House, Manitoba, by The IBI Group, Toronto, for CMHC, February 1987

Drying Characteristics in Timber Frame Walls of Low-Rise Residential Housing - Final Report, by Rowan Williams Davies & Irwin Inc. and Scanada Consultants Ltd, for CMHC, April 1988

Basement Condensation: Field Study of New Homes in Winnipeg, UNIES Ltd., for CMHC, December 1987

PART 2: MOISTURE RESEARCH IN THE UNITED STATES OF AMERICA

1. NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

1.1 Future work : Guidelines for moisture control in hot and humid climates.

A significant number of mold and mildew problems have been reported at the interior surfaces of buildings located in hot humid climates by the Hotel/Motel Association. With the cooperation of members of the Hotel/Motel Association, several walls will be identified that have serious moisture problems in hot humid climates. The seasonal moisture performance of these selected walls will be analyzed using the NIST Moisture Transfer Model. Using Weather Years for Energy Calculation (WYEC) hourly outdoor weather data, the average moisture content of the wall components will be predicted as a function of time of year. A sensitivity analysis will be conducted to identify parameters which have a significant effect on moisture performance. Among the parameters which will be analyzed are the indoor temperature and humidity, the vapor resistance and air permeability of exterior parts of the wall, and the vapor resistance of interior parts of the wall. Limits for the significant parameters that maintain moisture contents in the wall below acceptable levels will be determined. These limits will be offered as recommended design practices.

Measure capillary transport properties for common building materials.

Capillary moisture transfer property data for common building materials are lacking in the literature. The development of capillary transfer data would considerably extend the accuracy and usefulness of the NIST Moisture Transfer Model.

Capillary property measurements will be carried out for the following building materials: gypsum board, pine, mortar, microfine particle board, and plywood. For each of the materials, the following measurements will be carried out:

1) Capillary (Suction) Pressure. Capillary pressure curves will be obtained using the centrifuge technique and the capillary rise technique. Separate capillary pressure curves will be measured for test specimens initially dry and initially wet. An attempt will be made to reduce the above capillary pressure measurements to a single correlation using the Leverett j-function. Such a correlation would permit the capillary pressure for other building materials to be estimated based upon much more simple measurements of liquid permeability and porosity.

2) Liquid Diffusivity. Methods to measure liquid diffusivity in capillary porous building materials covering a wide range of saturations are under investigation. After a through literature survey covering techniques used by soil physicists, ground water hydrologists, and building scientists, a steady flux method is being developed. The flux of liquid water through samples of building materials exposed to a reservoir of water on one side and to dry air on the other is measured over several days. After the liquid flux is determined, the material sample is sliced into approximately 5-mm-thick sections. The moisture content of each section is found gravimetrically. The liquid diffusivity is then determined from the quotient of the measured mass flux over the moisture content gradient.

   Preliminary results for gypsum board samples indicate that the liquid difusivity is an exponential function of moisture content and varies by several orders of magnitude over the moisture contents found in service. This result agrees with previously published measurements of similar capillary porous materials. Measurements of microfine particle board, pine, plywood, and mortar are currently underway.

   Using the data resulting from the above measurements, the unsaturated liquid permeability for the materials will be calculated.

Convert the NIST moisture transfer model into a user-friendly tool for building designers and engineers.

The NIST previously developed a distributed-capacity, finite-difference model that predicts the combined transfer of heat and moisture in multilayer construction under non-steady-state conditions. The model includes vapor diffusion, capillary, and convection transfers (i.e., transfer by air infiltration and exfiltration), and includes the important couplings between heat and moisture transfer. This model is capable of simulating the moisture performance of a wide range of constructions, and it uses weather data from WYEC.

The NIST Moisture Transfer Model will be down loaded to a personal computer and converted into a user-friendly tool for building designers and engineers.

Validate the NIST moisture transfer model using the Calibrated Hot Box.

Twelve isolated wall sections will be installed in the NIST calibrated hot box. These wall sections will be exposed to cold winter conditions at their exterior surfaces and typical indoor conditions (i.e., $23^{o}C$ and 50%rh) at their interior surfaces. The moisture accumulation within the layers of the construction will be measured as a function of time and compared to corresponding predicted values using the NIST Moisture Transfer Model. The wall sections will subsequently be exposed to warm conditions at their exterior surface in order to produce drying. The decrease in moisture content of the layers will be measured and compared to predicted values using the Model.

1.2 Current work:

Water-Vapor Permeability Measurements of Common Building Materials, D.M. Burch, W.C. Thomas, and A.A.. Fanney, prepared for ASHRAE symposium on measurements of moisture properties, ASHRAE 1992

An improved technique is presented for measuring the water-vapor permeability of building materials. The permeability is plotted as a function of the average relative humidity imposed across the specimen. Separate measurements are carried out at $24^{o}C$ ($75^{o}F$) and $7^{o}C$ ($44^{o}F$), thereby showing the effect of temperature on permeability. Mathematical relations are presented that convert permeability into the diffusivity for the moisture content gradient and the diffusivity for temperature gradient.

Separate experiments are carried out to measure the moisture resistance of the air films on opposite sides of the specimen. Analytical procedures are presented for removing the effect of the air film resistances from the permeability measurements. This technique was used to measure the water-vapor permeability of ten common building materials.

An Analysis of Moisture Accumulation in a Wood-Frame Wall Subjected to Winter Climate, D.M. Burch and W.C. Thomas, prepared for ASHRAE/DOE Ext. Env. V, Dec 7-11,1992 and NISTR report.

A transient, one-dimensional, finite-difference model is presented for predicting the coupled transfer of heat and moisture in a multilayer plane wall under non-isothermal conditions. The model can predict moisture transfer even when the diffusion is affected by the capillary flows. It can also account for convective moisture transfer in cavities which may be convectively coupled to indoor and outdoor air.

This model is subsequently used to predict the time-varying average moisture content in the sheathing and siding of a wood-frame cavity wall as a function of time of year. Results are shown for a mild winter climate (Atlanta, GA), an intermediate winter climate (Boston, MA), and a cold winter climate (Madison, WI). The indoor temperature is maintained at 21^{o}C, and separate computer runs are carried out for indoor relative humidities of 35% and 50%.

The effect of several construction parameters on the winter moisture accumulation are investigated. The parameters include the interior vapor retarder permeance, sheathing permeance, exterior paint permeance, indoor air leakage, and the amount of cavity insulation.

Indoor Ventilation Requirements for Manufactured Housing, D.M. Burch, NISTIR 4574, May 1991

A mathematical analysis revealed that the ventilation provided by natural infiltration is inadequate. The study recommends that both single-wide and double-wide mobile homes be equipped with mechanical ventilation equipment having a minimum installed capacity of 0.026 m^3/s (55 ft^3/min). It was found that considerably larger ventilation rates are needed to prevent condensation on single-pane windows. Therefore, it is recommended that double-pane windows be required in all heating climates.

1.3 Bibliography:

The Effect of Moisture on the Thermal Conductance of Roofing Systems, L.I. Knab, D.R. Jenkins, and R.G. Mathey, NSB Building Science Series 123, April 1980

Experimental Validation of a Mathematical Model for Predicting Water Vapor Sorption at Interior Building Surfaces, W.C. Thomas and D.M. Burch, ASHRAE Transactions, 1990, Vol 96, Part I, 3357

Transient Moisture and Heat Transfer in Multi-Layer Non-Isothermal Walls - Comparison of Predicted and Measured Results, D.M. Burch, W.C. Thomas, L.R. Mathena, B.A. Licitra, D.B. Ward, Proc. ASHRAE/DOE Ext. Env. IV, 1989

2. COLD REGIONS RESEARCH AND ENGINEERING LABORATORY (CRREL)

Moisture research at CRREL has been focused on roofs. Methods of finding wet insulation in membrane roofs have been developed and incorporated into roof maintenace management systems. Laboratory studies have developed relationships between the moisture content of common roof insulations and their insulating ability. Other studies have explained the importance of controlling air leakage, the value of vapor retarders and when and where ventilation is of benefit. Maps and other guidelines for eliminating moisture problems in roofs have been developed.

New Wetting Curves for Common Roof Insulations, Wayne Tobiasson, Alan Greatorex and Doris Van Pelt, 1991 International Symposium on Roofing Technology

Specimens of common roof insulations were placed in an apparatus that creates thermally driven vapor ingress and subsequent condensation inside the materials. The specimens were periodically removed from this apparatus, weighed, wrapped in a thin plastic film and then tested in a thermal conductivity instrument and returned to the apparatus for further wetting. Some insulations accumulated moisture rapidly, but others gained very little moisture even after years of testing.

Vapor Retarders for Membrane Roofing Systems, Wayne Tobiasson, Proc. 9the Conf. on Roofing Technology, National Roofing Contractors Association, 1989 or reprint from U.S. Army Corps of Engineers, CRREL, Hanover, NH

The potential for condensation in roofing systems is related to the climate outdoors and the temperature and relative humidity indoors. Maps and graphs have been developed to determine when and where vapor retarders should be installed. In most cases, vapor retarders should have a perm rating of 0.5 or less. Since air leakage, not vapor diffusion, is the primary mechanism behind condensation problems in buildings, air leakage paths must be sealed. This is difficult to achieve in framed roofing systems but relatively easy to accomplish in compact roofing systems.

When membranes are loose laid, air leakage potential increases and condensation problems may result. When the lower layer of insulation is mechanically attached to the deck, it is often best to place the vapor retarder above that layer of insulation where it is not penetrated by fasteners. Potential vapor traps are created in the insulated layer between waterproofing membranes and vapor retarders in compact roofing systems, but there is no need to ventilate these areas.

Bibliography:

Moisture Gain and Its Thermal Consequence for Common Roof Insulations, Wayne Tobiasson and John Ricard, Proceedings 5the Conference on Roofing Technology, 1979, reprint: US Army, Corps of Engineers, Cold Regions Res. and Eng. Lab. Hanover, NH

Venting of Built-up Roofing Systems, Wayne Tobiasson, NBS-NRCA 6the Conference of Roofing Technology, 1981, or reprint from CRREL

Locating Wet Cellular Plastic Insulation in Recently Constructed Roofs, Charles Korhonen, Wayne Tobiasson, Proceedings of SPIE- The International Society for Optical Engineering, volume 371, Thermal Infrared Diagnostics (Thermosense V), 1982

Can Wet Roof Insulation Be Dried Out?, Wayne Tobiasson, Charles Korhonen, Barry Courtermarsh, and Alan Greatorex, ASTM STP 789, 1983, pp. 626-639

Comparison of Aerial to On-the-Roof Infrared Moisture Surveys, Charles Korhonen, Wayne Tobiasson, Alan Greatorex, Proceedings of SPIED- The International Society for Optical Engineering, volume 446, (Thermosense VI), 1983

Condensation Control in low-slope roofs, Wayne Tobiasson, Workshop on Moisture Control in Buildings,1984, Building Thermal Envelope Coordination Council (BTECC), 1984, reprinted by the US Army, CRREL, Hanover, NH.

Vapor Drive Maps of the U.S., Wayne Tobiasson and Marcus Harrington, ASHRAE/DOE/BTECC Conf. Ext. Envelopes of Building III, 1985,

Wetting of Polystyrene and Urethane Roof Insulations in the Laboratory and on a Protected Membrane Roof, Wayne Tobiasson, Alan Greatorex, and Doris Van Pelt, ASTM STP 922, Am. Soc. for Testing and Materials, Philadelphia, 1987, pp. 421-430

Method for Conducting Airborne Infrared Roof Moisture Surveys, Wayne Tobiasson, Proceedings of SPIE - The International Society for Optical Engineering, volume 934, Thermal Infrared Sensing for Diagnostics and Control (Thermosense X), 1988

Vapor Retarders to Control Summer Condensation, W. Tobiasson, P.E., Thermal Perf. of the Exterior Envelopes of Buildings IV, ASHRAE/DOE/BTECC/CIBSE, Conf., 1989

Roofer: An Engineered Management System (EMS) for Bituminous Built-up Roofs, David M. Bailey, Donald E. Brotherson, Wayne Tobiasson, Al Knehans, Proc. 9 Conf. Roofing Technology, NRCA, 1989, or US ARMY Corps of Engineers Construction Engineering, Research Lab., USACERL Technical Report M-90/04, December 1989

Roof Moisture Surveys: Yesterday, Today and Tomorrow, Wayne Tobiasson and Charles Korhonen, Second International Symposium of Roofing Technology, 1985

3. USDA, FOREST SERVICE, FOREST PRODUCTS LABORATORY

Moisture in Walls of Manufactured Housing

The main objective of this research is to determine the relative importance of indoor humidity control and wall construction details to moisture accumulation in walls of manufactured homes.

We have constructed a special building and installed two identical sets of ten wall panels with various construction details. One set is exposed to moderate indoor humidity, the second set to high indoor humidity.

We are investigating the following questions:

- Is cavity ventilation effective in preventing condensation or promoting dryout?
- What is the effect of air leaks on air and moisture movement into the wall?
- What is the effect of indoor humidity control on moisture levels in walls and which preventive construction details are necessary even when humidity is controlled?

After considerable delays due to problems with instrumentation, this winter will be our first season to collect a full data set of moisture/temperature conditions and air pressures across the walls.

Humidity control in Manufactured Housing

This study focuses on humidity control in manufactured housing. We have measured indoor temperatures, humidities and ventilation rates in six homes, five of which were occupied. We are analyzing the data to obtain values for average moisture generation and moisture storage. This will enable us to evaluate the effect of various ventilation strategies on indoor humidity with the help of a simple mathematical model.

Attic Humidity Model

We have developed a mathematical model to calculate temperatures, humidity, and moisture content of the attic air and roof sheathing. The model allows evaluation of the effects of attic ventilation and other construction details. We are currently in the process of verifying the model with measured data from the University of Illinois, Small Homes Council-Building Research Council.

Future Research

Future research will likely continue to focus on the relationship between air movement and moisture accumulation. Likely areas of research will be: air barrier placement and ventilation of roofs. Other related areas of future studies are: evaluation of the "Duff" wood moisture sensor and installation of wood siding.

Bibliography:

Moisture Movement and Control in Light-Frame Structures, Gerald E. Sherwood, Anton TenWolde, Forest Products Journal 32(10):69-73, 1982

Condensation Potential in High Thermal Performance Walls - Cold Winter Climate, G.E. Sherwood, Madison, WI: U.S. Department of Agriculture, Forest, Service Forest Products Laboratory, 1983

Instrumentation for Measuring Moisture in Building Envelopes, A. TenWolde, G.E. Courville, ASHRAE Transaction, v. 91, part 2: 1985: 1101-115.

Steady-State One-Dimensional Water Vapor Movement by Diffusion and Convection in a Multilayered Wall, A. TenWolde, ASHRAE Trans., vol. 91(1): 1985, 322-342

Condensation Potential in High Thermal Performance Walls, Gerald E. Sherwood, Madison, WI: U.S. Dep. of Agriculture, Forest Service, Forest Products Lab., 28 p.

Moisture Movement in Walls in a Warm Humid Climate, Anton TenWolde, H.T. Mei, ASHRAE/DOE ext. env. III: 1986, Am. Soc. Heating, Refr. and AC Eng, 1986: 570-

Moisture Damage in Manufactured Homes in Wisconsin, Anton TenWolde, In: Shuman, Everett C.; Achenbach, Paul R., eds. Building thermal envelope technology series. Washington, DC: Build..Thermal Env. Coord. Council, 87-103, 1988, Vol. 1

A Mathematical Model for Indoor Humidity in Homes During Winter, Anton Tenwolde, In: Symposium on air infiltration ventilation and moisture transfer proceedings, 1986, Building Thermal Envelope Coordinating Council; 1988: 3-32

Overview of Moisture-Related Damage in One Group of Wisconsin Manufactured Homes, J.L. Merrill, A.TenWolde, ASHRAE Transaction 1989, V. 95, Pt. 1.

Moisture Transfer Through Materials and Systems in Buildings, A. TenWolde, ASTM STP 1039, Am. Soc.for Testing and Materials,1989, pp. 11-18

4. VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

4.1 Current work:

In collaboration with researchers at the NIST, recent activities have emphasized modelling transient moisture transfer in composite wall structures and the measurement of the required material properties [1-4]. The emphasis of this research has been more toward moisture accumulation and the resulting potential for structural damage and surface biological problems than on thermal performance. The transfer mechanism include liquid movement by diffusion and capillary action.

The objectives of a research project in progress are to advance the predictive capability of our existing moisture transfer-accumulation model and to develop a new experimental approach for measuring the necessary material properties. The key features of the new experimental method are forced convection with externally conditioned air for maintaining simultaneous temperature and humidity differences across specimens. Our previous permeance measurements were based on the ASTM cup method with extensions. The extensions include using saturated salts for varying humidity difference and an experimental technique for separating the specimen permeance from the overall permeance which is normally measured. The new apparatus is designed to circumvent problems with salts migrating and attacking materials, the effects of strong humidity gradients in adjacent quiescent air layers, and difficulties in maintaining temperature differences across test samples. The apparatus consists of two transparent environmental chambers with the test material in between. The environment in each chamber is controlled with a miniature space-conditioning system to maintain target dry-bulb and dew-point temperature. Upon completion, data will be obtained for specimens of porous materials subjected to strong temperature and small humidity differences without the potential contamination and other problems resulting from the use of stagnant aqueous salt solutions.

Future plans include experimental and analytical work to resolve technical deficiencies in existing approaches to modeling moisture transfer. Recent experiments have shown that simple Fick's law relationships in terms of either moisture concentration or vapor pressure fail to account for observed results in non-isothermal porous systems. The simple moisture concentration model does not account for moisture migration in the direction of decreasing temperature. Experimentally, it has been shown that moisture transfer occurs in the absence of a vapor pressure gradient when a temperature gradient exists. Water vapor diffusion, a transfer mechanism in parallel with bound liquid movement by diffusion or capillary flow is not generally treated as a separate mechanism even in highly porous materials. Finally, an established theory and credible material properties for the transition regime between bound-liquid diffusion and liquid-capillary flow are not yet available. With experimentation and data from the new experimental apparatus, a new theoretical formulation for reconciling these deficiencies can be evaluated.

4.2 Reported work:

The transport of heat and moisture in a medium density insulation system was investigated experimentally and analytically[5]. This investigation, which emphasized heat loss in wetted roof insulation systems, was an early attempt to quantify the effect of moisture content on thermal conductance. The moisture transfer mechanisms were vapor diffusion through the porous quiescent air space. The heat transfer mechanisms were conduction and latent heat transfer i.e., the "heat pipe" effect.

An important observation was that the conductance of wetted insulation is a transient phenomenon which depends more strongly on moisture distribution than on moisture content. Under steady conditions with an applied temperature difference, the free moisture eventually migrates to the cooler side and the conductance approaches the dry value. The conclusion is that for the type of system studied, thermal conductance (or resistance) is not a unique function of moisture content. Future emphasis should likely be directed toward measuring basic material properties for the insulation system materials and using a mathematical model to simulate the moisture and thermal performance of various systems.

Bibliography

1. Burch, D.M. W.C. Thomas, L.R. Mathena, B.A. Licitra, and D.B. Ward, *Transient Moisture and Heat Transfer in Multilayer Non-isothermal Walls-comparison of Predicted and Measured Results, Proc. Thermal Perf. Exterior Envelopes IV,* December 1989.

2. Thomas, W.C. and D.M. Burch, *Experimental Validation of a Mathematical Model for Predicting Water Vapor Sorption at Interior Building Surfaces, ASHRAE Transactions,* Vol. 96, Part 1, 1990.

3. Fanney, A.H., Thomas, W.C., Burch, D.M. and Mathena, L.R., Jr., *Measurements of Moisture Diffusion in Building Materials,* Accepted for *ASHRAE Transactions,* 1991.

4. Burch, D.M. and W.C. Thomas, *An analysis of Moisture Accumulation in a Wood-Frame Cavity Wall Subjected to Winter Climate*, for *Proceedings of the Thermal Performance of the Exterior Envelopes of Buildings*, 1992.

5. W.C. Thomas, G.P. Bal, and R.J. Onega, *Heat and Moisture Transfer in a Glass Fiber Roof-Insulating Material, ASTM STP 789*, 1983, pp. 582-601.

5. FLORIDA SOLAR ENERGY CENTER, UNIVERSITY OF CENTRAL FLORIDA

5.1 Objectives:

The overall objective is to develop research capabilities needed for the analysis of building integrated solar cooling and dehumidification alternatives suitable for hot , humid climates prevalent in the southeastern United States.

The overwhelming majority of building moisture arrives in the conditioned zone through infiltration and internal generation. While, in typical residences heavy moisture loads are removed by the air conditioning systems, in passively cooled or energy efficient buildings remaining moisture loads may result in excessive relative humidity levels.

Methods of accurately evaluating moisture effects in buildings are generally lacking in the building energy analysis procedures. The Florida Solar Energy Center is therefore participating cooperative research that aims in developing mathematical modelling capabilities for simultaneous heat and moisture transport in buildings. This effort comprises a number of research projects with five major elements : moisture transport through materials and systems, analytical methods for modelling, radiant barrier systems, enthalpy exchange systems, integrated systems.

5.2 Current and recently completed work:

An Experimental Study of Building - Integrated Off-Peak Cooling Using Thermal And Moisture ("Enthalpy") Storage Systems, A.A. Kamel, M.V. Swami, S. Chandra, P.W. Fairey, *ASHRAE Transactions 1991*, Vol. 97, Pt. 2

An innovative cooling strategy, namely, building-integrated off-peak cooling, was experimentally studied. The approach was designed to shed air-conditioning load from peak demand periods by using both thermal and moisture storage in buildings. This paper presents results of room-scale experiments performed in two side-by side test cells where the building-integrated off-peak cooling strategy was tested. The experimental setup and configuration established for this purpose are described. Results from three sets of tests are then presented. First, a set of null tests shows that the rooms behave identically when subjected to identical inputs. In the second set of tests, thermal capacitance is added to one of the cells and the room conditions are compared. In the third test, both thermal and moisture capacitance are added to one cell. Results show that both thermal and moisture capacitance are needed to successfully incorporate building-integrated off-peak cooling in hot, humid climates, since humidity is as important as temperature in determining comfort. In general, when this strategy is employed, the required capacity of the air-conditioning equipment will not be increased.

Effect of Nonlinear Transport Coefficients on Combined Heat and Moisture Transfer in Solid,A.Kerestecioglu, and L. Gu *Journal of Heat Transfer*, (to be published).

A mathematical model has been developed to simulate combined heat and moisture transfer. The transport phenomena are solved by the finite element method, and details of this method and a comparison of two hypothetical cases and their analytical solutions are presented. The physical meaning of various transport coefficients used in this model and particularly the effect of non-linear transport coefficients on heat and moisture fluxes are discussed.

Study of a Combined Thermal and Moisture Storage System and an Analysis of phase Change in the Presence of Natural Convection, Ph.D. Thesis, Muthusamy V. Swami. Florida Institute of Technology, 1991

Phase change materials (PCM) provide excellent thermal storage. Certain fatty acids and oils are attractive candidates in this respect. Mixtures of these materials can be appropriately proportioned to obtain a desired solidification/melting range and can be easily packaged in existing wall systems. Surface coating of hygroscopic materials can provide the required moisture storage.

The first part of the work analyzes a thermal and a combined thermal and moisture storage system. The effect of key parameters on the surface temperatures, surface vapor densities, moisture content and discharge times are studied. Results show that, for the moist wall, the dimensionless thermal conductivity is a significant parameter affecting the exposed-surface temperature. Isotherm shape and dimensionless diffusivity have significant effect only at low conductivity values. All the parameters considered have significant effect on the surface water vapor density, with the dimensionless diffusivity having the most.

Next, solidification in the presence of natural convection is analyzed using the enthalpy formulation. The energy equation is modified to account for the enthalpy of phase change, and the momentum equations are modified to reduce the flow in the mushy region via Darcy's law. Results show that significant improvement in solidification rates are obtained with conducting walls around the cavity. They also show that low Prandtl and Stefan numbers, and transition widths improve solidification. Higher solidification rates are obtained with larger solid-to-liquid thermal conductivity ratios.

Experimental Determination of Combined Heat and Mass Capacitance Effects on the Dynamics of Room Scale Environments, Ph.D. Thesis, A.A. Kamel, Florida Institute of Technology, 1990

The effective moisture penetration depth concept is introduced in the research as a tool to simulate moisture transfer in building materials. The concept is used successfully in a computer code written by the author to simulate the rooms used in the experiments. The room conditions as well as the cooling loads are predicted and compared with the measured data. The results encourage the use of that concept as a good simple tool in building simulations in order to avoid errors in temperature, humidity, and load calculations. The effective penetration depth concept is shown to be more valuable when the buildings are exposed to large fluctuations in relative humidity.

Bibliography:

Effect of Desiccant Geometry on the Performance of the Desiccant Enhanced Nocturnal Radiative Cooling System, M. Swami, 1990 ASME International Computers in Engg. Conference, Boston, Massachusetts, August 5-9, 1990.

Combined Heat and Moisture Transfer In building and Structures, A.Kerestecioglu, M. Swami, L.Gu, Presented in the ASME Winter Annual Meeting, 1989

An Analytical Assessment of the Desiccant Enhanced Radiative Cooling Concept, M. Swami, P. Fairey, and A. Kerestecioglu,1990 ASME International Solar Energy Conference, Miami, FL, April 1-4 (1990).

Theoretical and Computational Investigation of Simultaneous Heat and Moisture Transfer in Buildings:
* Evaporation and condensation Theory, A. Kerestecioglu and L. Gu, ASHRAE Transactions, Vol. 96, 1990, Part 1, p455 - 464
* Effective Penetration Depth Theory, A.Kerestecioglu, M. Swami, and A. Kamel, ASHRAE Transactions, Vol. 96, 1990, Part 1, p.447-454

Incorporation of the Effective Penetration Depth Theory into TRNSYS, A. Kerestecioglu, and L. Gu FSEC-CR-303-89, December 1989,

Detailed Simulation of Combined Heat and Moisture Transfer in Building Components, A. Kerestecioglu, ASHRAE/DOE Envelope Conf. IV .1989 pp. 477-491

Computerized Material Moisture Property Data Base, A.Kerestecioglu, P. Brahma, and P. Fairey FSEC-CR-286-89, (October 1989).

Combined Heat and Moisture Transfer in Closed Cavities, A. Kerestecioglu, A., and M. Swami, AIChE Symposium Series, No. 269, Vol. 85, pp. 115-120, (1989).

Modeling Heat, Moisture and Contaminant Transport in Buildings: Toward a New Generation Software, A.Kerestecioglu, M Swami, P, Fairey, L Gu, and S.Chandra, Proc. Buildings Simulation '89, Int. Build. Performance Simulation Association, 3299 Rames Circle, Sacramento, Ca, 95821,p. 333-340

An Analytical Assessment of the Desiccant Enhanced Nocturnal Cooling Concept and the Design and Construction of the Diurnal Test Facility, M. Swami, R,Rudd, P.Fairey, S. Patil, A.Keresteciogiu, and S. Chandra,FSEC-CR-237-88, (February 1989).

Theoretical and Computational Investigation of Algorithms for Simultaneous Heat and Moisture Transport in Buildings, A.Kerestecioglu, M.Swami, R. Dabir, N. Razzaq, and P. Fairey,FSEC-CR-191-88, (January 1988).

Latent and Sensible Load Distributions in Conventional and Energy Efficient Residences, P.Fairey, A. Kerestecioglu, R. Vieira, M. Swami, and S.Chandra, Gas Res. Inst. Report, FSEC-CR-153-86, Florida Solar Energy Center, 1986.

Desiccant Enhanced Nocturnal Radiation - A new Passive Cooling Concept, P.Fairey, R. Vieira, and A. Kerestecioglu,10the Nat.Passive Conf. ASES,1985, ASES, 2400 Central Ave, Boulder, Co 80301,

Dynamic Modeling of Combined Thermal and Moisture Transport in Buildings: Effects on Cooling Loads and space Conditions, P.Fairey, and A. Kerestecioglu, ASHRAE Transactions, Vol. 91, Pt. 2 , 1985, p.461-472

The Detailed Prediction of Simultaneous Heat and Mass Transfer in Cavities, Ali Alp Kerestecioglu, Ph.D. Thesis, 1986 , Florida Institute of Technology

6. UNIVERSITY OF MINNESOTA

6.1 Current work : **Moisture Control**

A field study in a residential bathroom was conducted to measure the moisture generation rates from a shower and the effectiveness of three types of moisture removal mechanisms. More recent work has involved the development of a new testing method to measure the moisture permeability through building materials under various temperature and vapor pressure conditions. This test simulates the actual conditions found in building walls more closely than the traditions cup methods. Sorption isotherm data are also being obtained under various temperature conditions for common building materials.

Determination of Moisture Transport Properties for Common Building Materials: Methods and Measurements, J. S. Douglas, M.Sc.Thesis, U. of Minnesota, April 1991

To use advanced models that can predict the behavior of the building system over large time periods one must have a confidence in moisture transport property information for these models. This thesis describes a new method that builds upon the standard method for measuring water vapor transport, but adds flexibility of test conditions and improved accuracy of measurement. The thesis outlines the experimental apparatus and procedures, as well as instrument and methodological errors.

Filtration

Two studies on the performance of air filters have been made. The first study tested the filtration efficiency and pressure drop of nine different dust collectors used in industrial settings to filter nuisance dust prior to recirculating the cleaned air back into the working environment. A model was developed to predict the indoor respirable dust concentration using these air cleaners in a recirculated air system. The second study is evaluating the effect of media filters and electronic air cleaners on the concentration of viable particles in the indoor air.

Room Air Motion and Contaminant Transport

Air flow velocities and particle transport have been measured and predicted in tunnel clean rooms for a variety of configurations. More recent work has been to conduct a blind computational exercise in which contributors modeled the air flow and particle concentration distribution in a clean room. We conducted the corresponding experimental measurements simultaneously. We then compared the various contributed numerical solutions with the experimental data. Flow results agreed very well, particle concentration results did not agree as well. Current work is continuing on the measurement of room air flow and contaminant transport in office buildings. Flow visualization, air velocity, and concentration measurements are being made in a laboratory chamber and in the field for a variety of diffuser types, air flow rates, supply air conditions and office furnishing configurations.

Residential Kitchen Ventilation

Laboratory measurements have been made on overhead hood and downdraft exhaust equipment. Measurements include qualitative steam capture effectiveness, flow visualization and air velocity. A simple potential flow model was found to adequately describe the air velocity distribution near the exhaust provided that appropriate sources and sinks were incorporated. Publications and video tapes showing the flow visualization have been made.

Bibliography:

Field Measurements of Humidity Addition and Removal in a Room with a Shower, R. Gronseth, H. Han, T.H. Kuehn and J. Ramsey, Proc. IAQ '86, ASHRAE, 1986, pp 486-499

Heat and Mass Transfer in Occupied Buildings, T.H. Kuehn, Proc. 9the Int. Heat Transfer Conf., Jerusalem, Israel, Vol. 1, pp. 435-443 (1990), KN-28

Comparison of Measured and Predicted Airflow Patterns in a Clean Room, Thomas H. Kuehn, Virgil A. Marple, Hwataik Han, Dejang Liu, Ilango Shanmugavelu and Sadek W. Youssef, Proc. Inst. of Environmental Sciences, 1988, pp 331-336

Predicting Air Flow Patterns and Particle Contamination in Clean Rooms, Thomas H. Kuehn, J. Aerosol Sci., Vol. 19, No. 7, 1988, p 1405-1408

Computer Simulation of Airflow and Particle Transport in Cleanrooms, Thomas H. Kuehn, J. Environmental Sciences, Vol 31, No 5, 1988, p21-27

A Study of Airflow Patterns near Kitchen Range Exhaust Systems, Hwataik Han, Tom Kuehn, Mark Perkovich, James Ramsey, and Sadek Youssef, Proc. 40the Int. Appliance Tech. Conf., May 2-3, 1989

A Study of Kitchen Range Exhaust Systems, T.H. Kuehn, Ph.D., P.E., J. Ramsey, H. Han, M. Perkovich, S. Youssef, ASHRAE Transactions Vol 89. Pt.1,1989 p.744-752

7. PORTLAND STATE UNIVERSITY

The effect of exterior insulating sheathing on wall moisture, G.A. Tsongas, ASTM STP 1116, R.S.Graves and D.C. Wysocki Eds, ASTM, Philadelphia,1991

A field study of 86 newly constructed Washington and Montana homes was completed. Unacceptably high moisture levels were measured in the walls of a large percentage of the homes. However, the use of exterior insulating sheathing was found to greatly reduce wall moisture levels. The results of this study indicate that the use of exterior insulating sheathing is one way of providing additional wall insulation while at the same reducing the potential for wall moisture problems.

Bibliography:

A field test for correlation of wall air leakage and wall high moisture content sites, G.A. Tsongas and G.Nelson, ASHRAE Trans., V. 97, Part 1, 1991

Solar-driven moisture transfer through absorbent roofing materials, M.J. Cunningham, G.A.Tsongas, D. McQuade, ASHRAE Trans., 1990, V. 96, Pt.1

The Northwest Wall Moisture Study: A field study of excess moisture in walls and moisture problems and damage in New Northwest homes, G. Tsongas, Report for Bonneville Power Admin., March 1990

Field monitoring of the winter performance of a residential dehumidifier, G.A. Tsongas and R.S. Wridge, ASHRAE Trans., 1989, V.95, Pt.1

The effect of building air leakage and ventilation on indoor air humidity, G.A. Tsongas, Proc. of the Symposium, Building Thermal Envelope Coordinating Council, 1986

The Spokane Wall Insulation Project: A field study of moisture damage in walls insulated without a vapor barrier, G. Tsongas,Proc. ASHRAE /DOE/BTECC Conf. Ext.

Envelope III, 1985

A field study of moisture damage in walls insulated without a vapor barrier, G.A.Tsongas Proc. of DOE/ ASHRAE / Ext. Envelope I, 1979

A case study of the cause of moisture damage G.A. Tsongas, Proc. of the Symposium, Building Thermal Envelope Coordinating Council, 1986

8. Oak Ridge National Laboratory

Thermal and Hygric Roof (THR) Model Program User's Manual, W.A. Herlache, B.J. Dempsey, U. of Illinois, Urbana, Ill., ORNL/Sub/82-43122/2, January 1986

This report provides documentation on the use of the thermal and hygric roof (THR) model which was developed under contract entitled "Mathematical Modeling of Whole Roof System Performance". The report describes the computer program for predicting temperature and moisture distribution in roof systems.

This work is further documented in the reports entitled "Mathematical Modeling of Whole Roof System Performance" and "User's Manual for Program ROOF" . The latter report describes the computer program for determining mechanical stresses and strains in various roof components. Although the two programs are described separately, the output of the THR model constitutes input for the program ROOF.

Corrosiveness Testing of Thermal Insulating Materials - A Simulated Field Exposure Study Using a Test Wall, K. Sheppard and R. Weil, Department of Materials and Metallurgical Engineering, Stevens Institute of Technology, Hoboken, NJ, and A Desjarlais, Dynatech Scientific, Inc., Cambridge, MA, ORNL/Sub/78-7556/4, 1988

The test was conducted under controlled winter conditions in the absence of a vapor barrier. The house-wall simulation was achieved by construction a test panel containing 50 compartments into which various insulation materials and control of the sterile cotton were installed. Steel and copper coupons together with water-cooled copper pipes were embedded in the insulation and exposed for 6 months. While moisture was the primary factor in corrosion, some chemical activity from insulation components was also necessary. No corrosion occurred in the absence of insulation or in rockwool and glassfiber insulation. All cellulose insulations caused some corrosion. Mostly this was minimal but in a few cases severe pitting resulted. Such behavior of the cellulose did not correspond to previous laboratory test results in saturated insulation or leachants made from the insulation. However, laboratory testing of leachants made from some of the cellulose after the simulated wall test showed a change in pitting tendency, suggesting that time and/or exposure to moisture can change the corrosiveness.

Corrosion of Metallic Fasteners in Low-Sloped Roofs: A Review of Available Information and Identification of Research Needs, Walter J. Rossiter, Jr., National

Institute of Standards and Technology (NIST),, Center for Building Technology, Gaithersburg, MD 20899, Michael A. Streicher, Webster Farm, Wilmington, Willard E. Roberts, NIST, Report NISTIR 88-4008, February 1989

A study was conducted to summarize available information on the corrosion issue, and to identify the research needs. For various reasons, it was not possible to estimate the extent of the corrosion, for instance corrosion could not be established because of the inaccessibility of installed fasteners within roofs. In reviewing factors affecting fastener corrosion, water was the only one that stood out on the basis of the information obtained. Uniform corrosion (rust on some or all of the surface) was the predominant type that inspectors have observed in service. Nevertheless, some evidence of localized corrosion processes (e.g., crevice corrosion) has also been observed. Both types of corrosion may lead to loss of fastener securement in service. The results of the study indicated that there are three major gaps in the knowledge base: 1) evaluation test procedures for the corrosion resistance of fasteners are limited and need to be improved, 2) a data base on field performance of fasteners is lacking, and 3) non-destructive diagnostic procedures for assessing the condition of in-place fasteners are not available.

Other reports:

Heat and Mass Transfer Through Porous Media, S. Motakef, L.R. Glicksman, Massachussets Institute of Technology, Cambridge, MA, ORNL/sub/85-27486/2

Overview of the Applicability of Electrochemical Methods to Evaluation of the Corrosiveness of Residential Building Thermal Insulations with Proposed Cooperative Test Program, E.E. Stansbury, report: ORNL/Sub/87-B8240/1, October 1989

Assessment of Potential Techniques for In-SITU, Real Time Moisture Measurements in Building Envelope Systems - A Literature Survey, D. Whiting, Construction Technology Laboratories, Skokie, Illinois, report: ORNL/Sub/83-40122/1

A Capacitance Probe for Measurement of Moisture Content in Open Pore Thermal Insulations, S. Motakef, L.R. Glicksman, Massachusetts Institute of Technology, Cambridge, MA, published as ORNL report: ORNL/Sub/85-27486/1, January 1989

Investigation of Dynamic Latent Heat Storage Effects of Building Construction and Furnishing Materials, P.C. Martin and J. D. Verschoor, ORNL/Sub/86-22016/1, 1986

9. OTHER IMPORTANT CONTRIBUTIONS TO MOISTURE RESEARCH IN THE USA

8.1 Research publications

Laboratory and Field Investigations of Moisture Absorption and Its Effect on Thermal Performance of Various Insulation, F.J. Dechow and K.A. Epstein, ASTM STP 660, American Society for Testing and Materials , 1978, p 234-260

Thermal Performance of Various Insulations in Below-Earth-Grade Perimeter Application, G. Ovstaas, S. Smith, W. Strzepek, and G. Titley, ASTM STP 789, American Society for Testing and Materials, 1983, pp. 435-454

Laboratory Methods for Determining Moisture Absorption of Thermal Insulations, II: Comparison of Three Water Absorption Test Methods with Field Performance Data, A.O. Forgues, J. Thermal Insulation, Vol. 7, p128-137, October 1983

The crawl space, an underutilized conservation resource, J.W. Herr and V.V. Vercoe, Dow Chemical USA, 4the Int. Energy Efficient Build. Conf. Minnesota, Mi,1986

Moisture migration in buildings in hot/ warm, humid climates, H.T. Mei, Lamar U, 6the Symp on Improving Building Systems in Hot and Humid Climates, Dallas, Tx, 1989

The use of low-moisture-permeability insulation as an retrofit system - a condensation study, D.M. Burch, A.G. Contreras, S.J.Treado, ASHRAE Trans. Vol 85, Part II, 1979

8.2 Handbooks

Moisture Control Handbook: New, Low-rise residential construction, J. Lstiburek and J. Carmody, Oak Ridge National Laboratory, ORNL/Sub/89/SD350/1

This handbook first reviews how mold, mildew, and condensation occurs on building surfaces. Then, moisture movement in buildings is examined and the concept of acceptable performance is introduced. Once the basic concepts are outlined, specific moisture control practices and wall, foundation, and roof construction details for various climates are presented.

The most common surface-moisture-related problems are mold, mildew, and condensation. The single most important factor influencing these problems is relative humidity near surfaces. These problems are minimized by controlling both temperature and vapor pressure near surfaces.

Moisture moves because of gravity and diferences the pressure of vapor (vapor diffusion) or capillary liquid pressure (capillary flows) or even air movements. Each of these mechanisms can act independently and therefore must be controlled during both design and construction stages of the construction. There are three strategies to minimize the risk of moisture damage: control entry, control accumulation, and removal. Specific moisture control practices are presented for heating, cooling, and mixed climates. Construction details are given for above-grade walls, foundations, and roofs in each climate.

Building Foundation Design Handbook, Kenneth Labs, Undercurrent Design Research, New Haven, Connecticut; John Carmody, Raymond Sterling, and Lester Shen, Underground Space Center, University of Minnesota; Yu Joe Huang, Lawrence Berkeley

Laboratory, and Danny Parker, Florida Solar Energy Center, report: ORNL/Sub/86-72143/1, May 1988

This handbook provides a simplified method for estimating the cost-effectiveness of foundation insulation measures in all regions of the United States. It also provides information on acceptable practices of subdrainage, waterproofing, structural integrity, thermal efficiency, and radon and termite control. All of these systems related to foundation design are integrated into a series of construction details for basements, crawl spaces, and slab-on grade foundations.

The primary focus of the handbook is on new residential construction, but some of the information also pertains to small commercial buildings and retrofit applications. The intended audience for the handbook is architects, engineers and other residential designers, including builders who make foundation design decisions. to address this diverse audience, the handbook is in two parts: (1) a summary of cost-effective insulation levels, recommended practices, and construction details for three basic foundation types, and (2) technical reference information, including separate chapters on thermal design, subdrainage, waterproofing, structural design, and radon and termite control.

ASTM Manual on Moisture Control in Buildings, H.R. Trechsel (editor), in preparation , expected by mid-1992

This manual comprises five parts: Fundamentals, Application, Construction Principles and Recommendations, Implementation Mechanisms, and Future Directions. Each of 26 chapters, which are written by different authors, aims at presenting the state of the art in moisture control or design practices.

The first part review the sources of moisture, the mechanisms of moisture transport and these properties of materials which are used in calculation of drying or wetting (one chapter illustrates the application of computer modelling). Furthermore, moisture effects such as mold and mildew or the reduction of thermal performance caused by moisture are discussed.

In the second part of the manual, air infiltration and ventilation, mechanical equipment, heating and cooling are discussed. Furthermore, large number of case histories will illustrate the need for trouble shooting at different stages of the design process. The design process is, however, addressed in the third part, entitled "construction principles and recommendations. this part comprises seven chapters, each addressing a different components or systems (roofs, residential, commercial, high rise, mobile or manufactured homes, prevention and repair).

Remaining two parts address codes, test methods and material standards as well as the moisture oriented research, as they appear today and their future needs. Since the manual, as all the ASTM documents, would be subject to 5 year revision, this manual could not only synthesize today's information on the the design practice, standard development and research, but also provide a vehicle for the future development and implementation of more effective moisture control strategies.

CONCLUDING REMARKS

If one compares the scope of moisture research shown in Figure 1 with the above review of research projects, one could see progress in most of the field. Yet some of the researchers does not appear entirely satisfied.

In closing of his review, professor John Timusk stated : "My overall perspective about moisture work is that too much is done on analysis and modelling, too little on the development of designs which provide a high level of thermal comfort, excellent air quality, are cheap to build, consume little energy and are immune to moisture problems."

Dechow and Epstein, in the abstract of their paper stated that: "Much work has been done in Europe, Canada, and the United States with respect to the effect of moisture on the thermal efficiency of various insulations. However, very little research has been done to orient the laboratory test methods to the actual field conditions in which the various insulations will be used'.

One must bear in mind, however, that , as a rule, the orientation towards the actual field conditions or assessment of the material performance in the system exceeds a capability of a separate researcher. To combine capability of advanced material testing, computer modelling and laboratory experiments under controlled climatic conditions to verify these models with the full scale laboratory and field testing, as a rule, is beyond capability of the most research laboratories. The conclusion is obvious, to be efficient researchers must work together.

Both professor Timusk and Dow's researchers call for orienting the academic research towards practice. The importance of this issue can not be overstated now when the research produces more "data" than anyone can possibly use. The editor of this review had to leave out 70 percent of available information, delete many comments related to the publication list, and the 30 percent took the space of a double length paper. Why then, with such an affluence of information, some of us make claims that the designer and architect or construction practice are badly served. What is wrong with our communication lines? Do we try to respond to this challenge?

In the introductory remarks, the changing situation of the academic research on moisture control in buildings was mentioned. Indeed , many of the leading research groups understood that to have a practical impact one must combine computer modelling, small and full scale testing, demonstration and field testing with the solid understanding of physics, material science and engineering. And since none of these groups have all these elements, in pursuit of practical solutions, research institutes must cooperate with others. Cooperations such as NIST working together with VPI, NRC having joint research program with VTT(Finland) and FSEC permit to address much broader scope of the research and achieve the results much faster. But even this level of cooperation may be insufficient.

In my view, while the research founding organizations put enough stress on communication between research community and their clients (user oriented handbooks, software guides etc), they do not spent enough effort to organize research reviews or state-of-the art workshops for the sake of researchers alone. It should be recognized that a meeting with a few invited speakers and long discussion periods are as important for the funding organization as for the younger researchers to learn the state of the art. The funding organizations must be able to choose a correct research approach and ensure that money is spend effectively. One may give examples when one workshop with a few invited speakers and several panel discussions (such as Moisture Control in Buildings workshop organized in 1984 by BTECC) contributed more the state-of-the-art awareness than a few of the large international symposia.

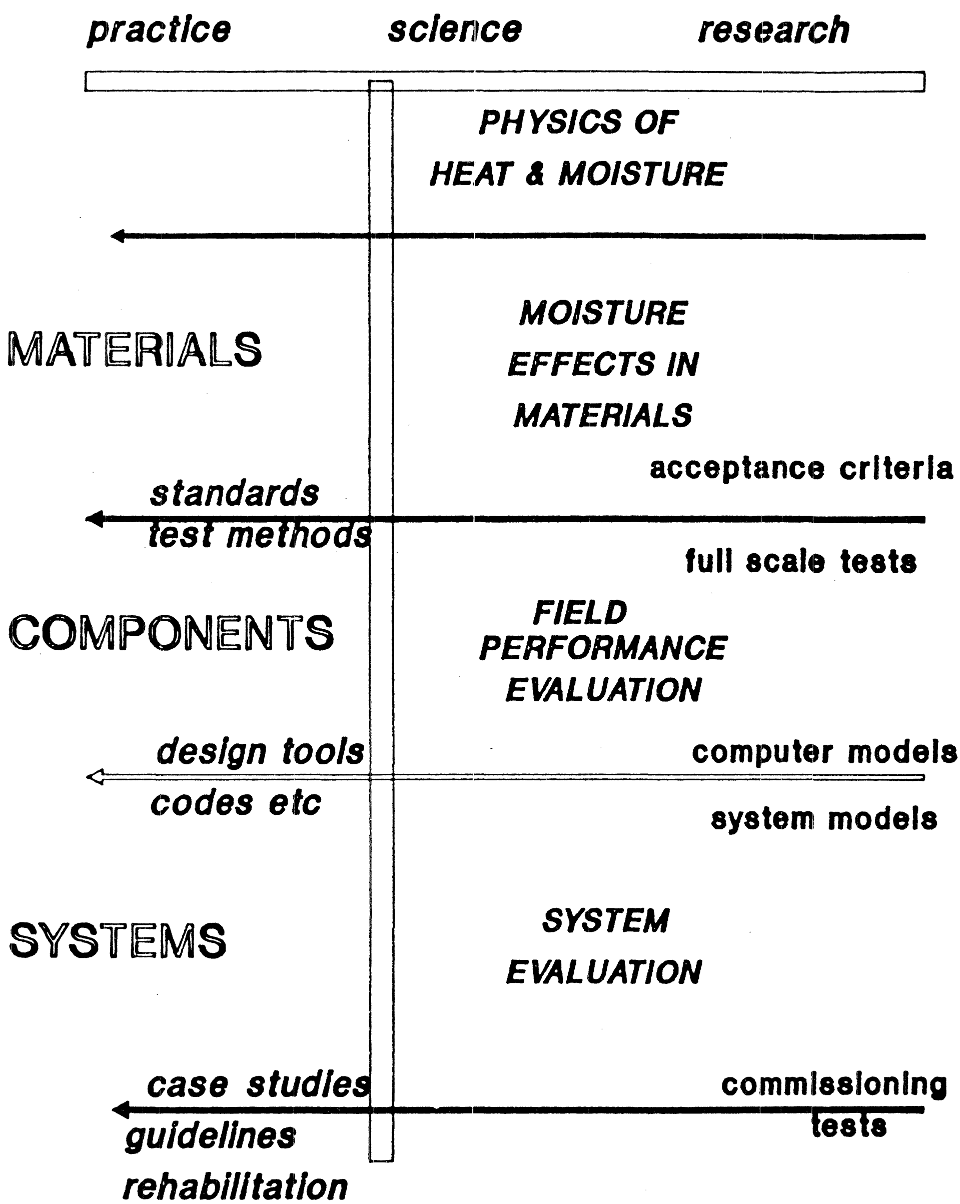


Fig 1. Scope of moisture research.

Vagn Korsgaard
Thermal Insulation Lab., Technical University of Denmark
Denmark

UTILIZING CAPILLARY SUCTION FABRIC TO PREVENT MOISTURE ACCUMULATION IN THERMAL INSULATION OF COLD, IMPERMEABLE SURFACES

ABSTRACT

To prevent moisture accumulation in the thermal insulation material of cold impermeable surfaces, such as cold water pipes or flat roof membranes, the only remedy in general use so far is a vapour retarder membrane on the opposite side of the insulation. In practise it is recognized that a vapour retarder is not a perfect vapour barrier. For flat roofs, it has therefore until recently been common practise also to establish ventilation with outdoor air as a further remedy to prevent moistening of the insulation. However, experience has shown that ventilation openings often, due to stack and wind effect, will result in moist room air entering the roof system and increase the moisture content of the insulation material. Nor is it possible to establish a perfect vapour barrier on the surface of the insulation of cold pipes. Therefore fibrous insulation material, such as mineral wool which has a very high permeability, is not used. The much more expensive syntetic foams og glass foams with closed cells are used. After 10-20 years these types of insulation will also be soaked with water/ice and must be replaced.

In the paper two new innovative concepts to prevent moistening of the insultion of cold surfaces are introduced. One concept for flat roofs, and another one for cold pipes. Both concepts are based on the capillary suction properties or wicking action of fibrous fabrics.

FLAT ROOFS, MEMBRANE ROOF SYSTEMS

Preamble

The way we usually design and build a flat roof system with a waterproof vapour retarder has to my opinion, been wrong, which has been documented many times in real life.

What we actually are doing is installing the insulation material in a bath tub with the plug securely tightened, at least when we are talking about warm deck roofs. Perhaps less securely tightened when we compare with a cold deck roof.

Although we install a cover over the bath tub, we cannot prevent our Lord from opening the shower during construction, nor later when leaks develop in the roofing.

The result is that rain water sooner or later will enter the roof system and stay trapped between the roofing and the waterproof traditional vapour retarder with the well known consequence of poor insulation value and risk of deterioration. In principle, the remedy is to leave the plug-hole open. In practice this solution is too primitive, and I shall in my talk describe a more sophisticated solution, the WPVR-concept.

THE WATER PERMEABLE VAPOUR RETARDER CONCEPT

Migration of water into a membrane roof system by diffusion during the cold season shall be reduced to an amount which will not increase the moisture content to a critical value for fungal attack in timber based roof systems, cause corrosion on metal parts or decrease the insulation value significantly. This means that a vapour retarder with a sufficiently low permeability shall be installed below the insulation.

In Figure 1 is shown the development over a Danish heating season of the moisture content of the 12.5 mm structural plywood deck in dependence of the diffusion resistance of the vapour retarder. The PC-program MATCH has been used.The roof is insulated with 200 mm mineral wool on 12 mm gibson board ceiling panels. It is seen that a Z-value of app. 10 is sufficient to prevent the moisture content of the plywood to increase to the critical value of 20% for fungal attack at the end of the heating season when drying will start. The moisture in the roof system will only dry out of the system if the vapour retarder is water (condensate) permeable. As the vapour retarder is not perfect due to overlaps, joints and faults, a Z-value of 50-100 should be preferred.

To prevent vapour from migrating into the roof systems by convection through leaks in the vapour retarder, both warm and cold deck roof systems shall be unventilated, making use of the air tightness of the roofing.

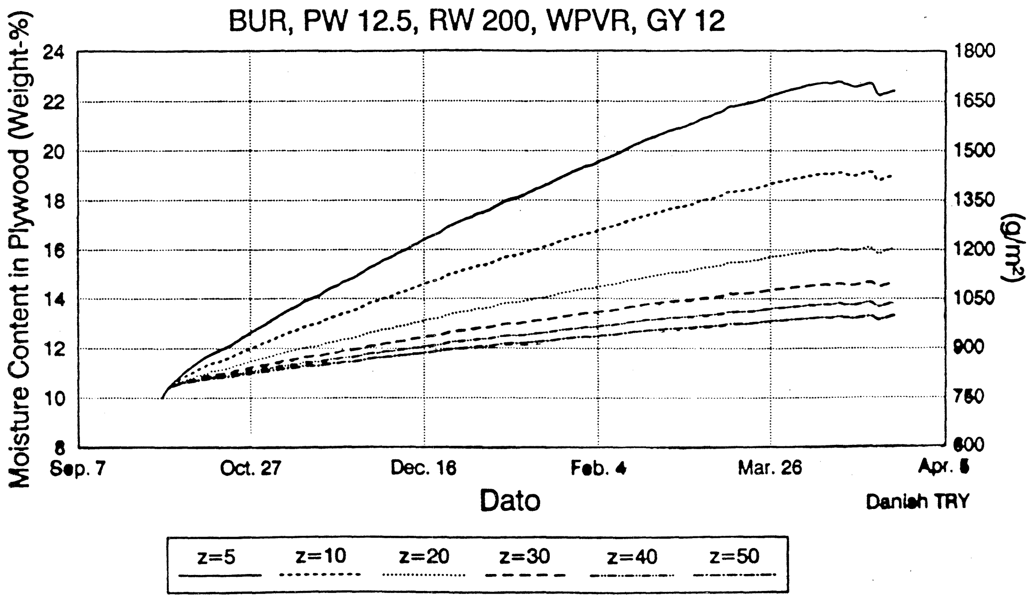


Figure 1. Moisture content of the structural plywood deck of an insulated cold deck roof system in dependence of diffusion resistance (Z Gpa m² s/kg) of the vapour retarder.

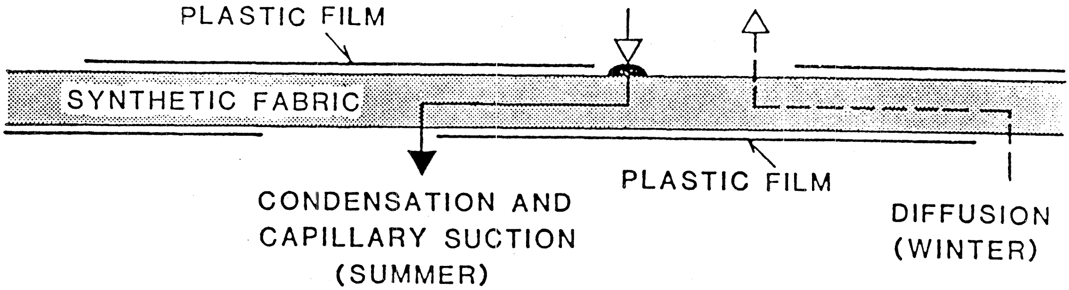


Figure 2. Design of the water permeable vapour retarder (WPVR).

To allow moisture trapped in the roof during construction or later through leaks in the roofing to migrate out of the roof system, the vapour retarder membrane shall be permeable to water (WPVR). Such a WPVR membrane (Hygrodiode ®) has been developed a few years ago and is patented in most industrialized countries.

In the first three years of marketing, the Hygrodiode ® has been installed in approximately 250 000 m^2 of roof systems in Denmark and Austria where it so far has been marketed.

The water permeable vapour retarder (WPVR), Figure 2, consists of synthetic fabric with good capillary suction properties sandwiched between stripes of diffusion tight plastic film. The stripes are staggered with an overlap. The size of the overlap and the thickness of the fabric together with the permeance of the plastic film stripes determine the diffusion resistance of the WPVR. With a fabric thickness of 0.3 mm, an overlap of 60 mm, a film width of 180 mm and a permeance of 0.2 ng/m^2sPa the diffusion resistance of the WPVR (Hygrodiode ®) is approximately 100 $GPam^2s/kg$ corresponding to an 0.05 mm PE-film. This means that less than 100 g/m^2 of moisture will diffuse through the membrane during a typical northern European winter.

Moisture trapped or migrating into the roof system will accumulate directly under the roofing during winter. When the sun heats the roofing, the partial saturation pressure will increase drastically with temperature and drive the moisture by diffusion through the insulation layer and it will condense on the relatively cold Hygrodiode membrane. By wicking action the condensate will pass through the membrane to the supporting deck and migrate into the underlying room by capillary suction and evaporation.

The draining capacity with ponding water on the WPVR (Hygrodiode ®) has been measured to be 1200 g/mh, and by wicking action, 40 g/m^2h, Figure 3.

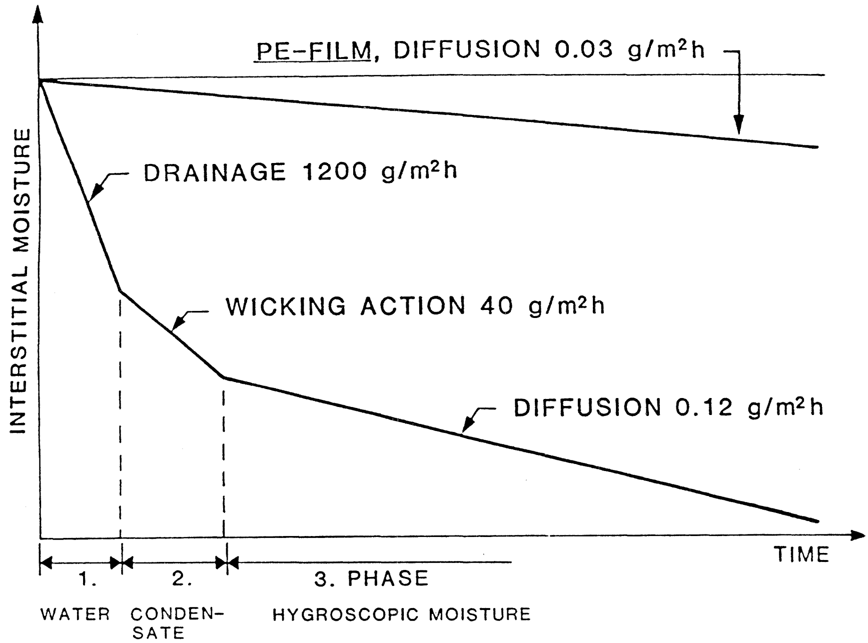


Figure 3. Drying capability of the water permeable vapour retarder, Hygrodiode ®.

When summer condensate is formed on the WPVR, its moisture resistance will be the least of the resistances of all the materials in the roof cavity. Thus, a drying potential may be defined as the amount of moisture which is able to migrate through the insulation material in the cavity. When there is moisture present at the top of the roof and some of it has migrated to the bottom and condensed on the WRVP, the driving potential for the vapour flow through the insulation is the difference between saturation vapour pressures on each side of the insulation. At the bottom of the insulation, the temperature is usually close to 20°C. The temperature at the top is determined by the ambient temperature and the amount of solar radiation. Knowing this temperature, the drying potential may be determined from a diagram of saturation vapour pressures (Figure 4). In the figure, the difference between vapour pressures at the top and bottom of the insulation has been divided by the vapour resistance of 200 mm mineral wool and 150 mm expanded polystyrene to give two axes from which the drying rates may be read. Note the drastic change in drying potential that results from small increases in the roof surface temperature from around 50°C.

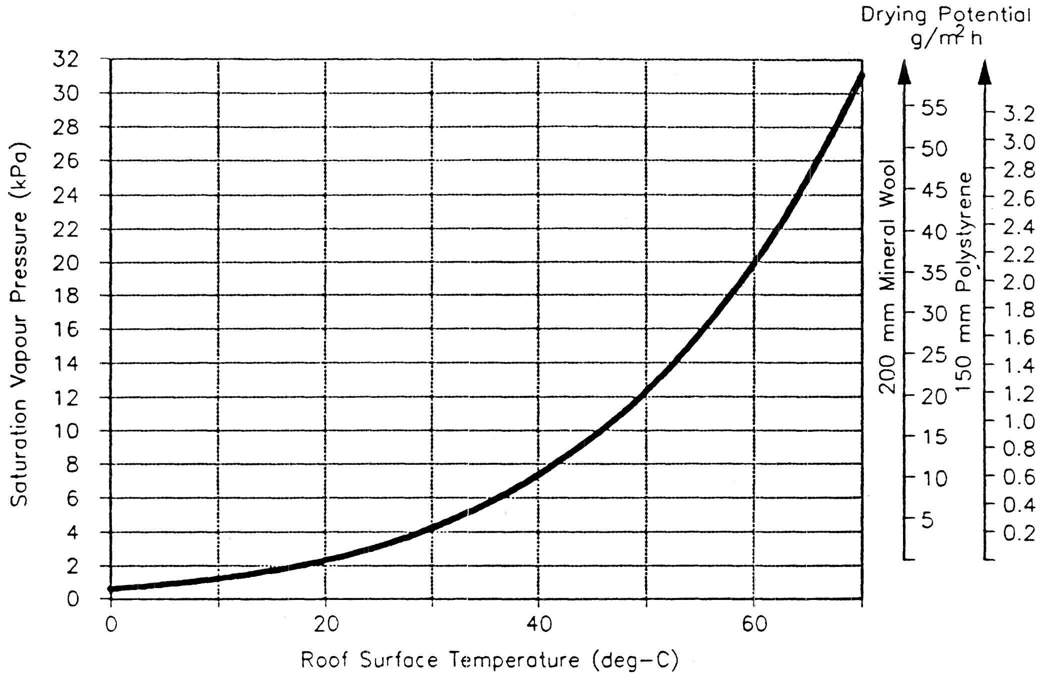


Figure 4. Use of diagram of saturation vapour pressures to determine the drying potentials through different insulation types using the WPVR concept.

TEST HUT

A small test hut has been built at the Technical University of Denmark. The building consists of two rooms. One room was kept at typical dwelling conditions for temperature and humidity, i.e. 20°C and 3 g more moisture per cubic meter in the indoor than in the outdoor air. The other room was kept constantly at 20°C and 60% RH. The temperatures of both rooms were allowed, however, to exceed 20°C in the summer as no cooling was provided.

The roof of the test hut had 8 rectangular holes, each 35 by 40 cm, over each of the rooms. Different roof specimens with the Hygrodiode® as vapour retarder were loacated in each of these holes as shown in Figure 5.

The specimens were wrapped in an envelope of heavy polyethylene on all but the bottom side with the vapour retarder. The sealing between the Hygrodiode® and the polyethylene wrap was done by carefully taping the two materials together. The specimens were mounted so that they could be pulled down and weighed regularly.

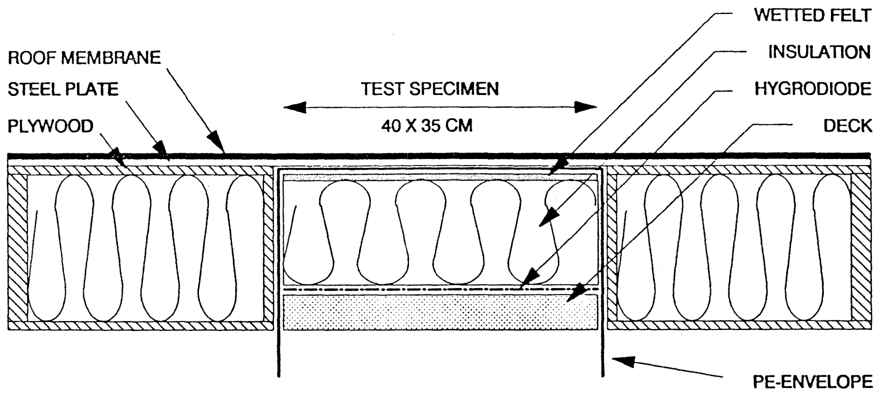


Figure 5. Cross section of one of the warm deck roof specimens for the field test with the Hygrodiode ® vapour retarder.

Above the specimens was a dark roofing of bitumen strewn with granulated slate. The membrane was supported over the specimens by a steeel deck. The materials used in the specimens were 150 mm of mineral wool or expanded polystyrene for the insulation and either a cold deck of 12.5 mm plywood above the insulation or different types of warm decks under the insulation and vapour retarder. The warm deck constructions had a thin layer of felt inside the polyethylene wrap above the insulation. This felt and the plywood in the cold deck roof was immersed in water at the beginning of the experiment to absorb approximately 500 g moisture per square meter roof.

The experiment was started in May 1988, and the moisture contents of the specimens were followed during the following two summers and one winter. The materials in the specimens were oven dried by the end of the experiment, thus making it possible to determine the absolute moisture contents in the test panels.

TEST RESULTS

Results of the weighings are shown in Figure 6 for four of the test panels. Two of the panels are from the room with dwelling conditions while the other two are from the humid room. The materials in the test specimens are listed in the figure. Apart from the deck material two of the panels, one from each room, are practically identical. They are of the warm deck type and have mineral wool as insulation. The second panel from the room with dwelling conditions was insulated with expanded polystyrene, while the second panel from the humid room was a cold deck roof with plywood on the outer side of the insulation.

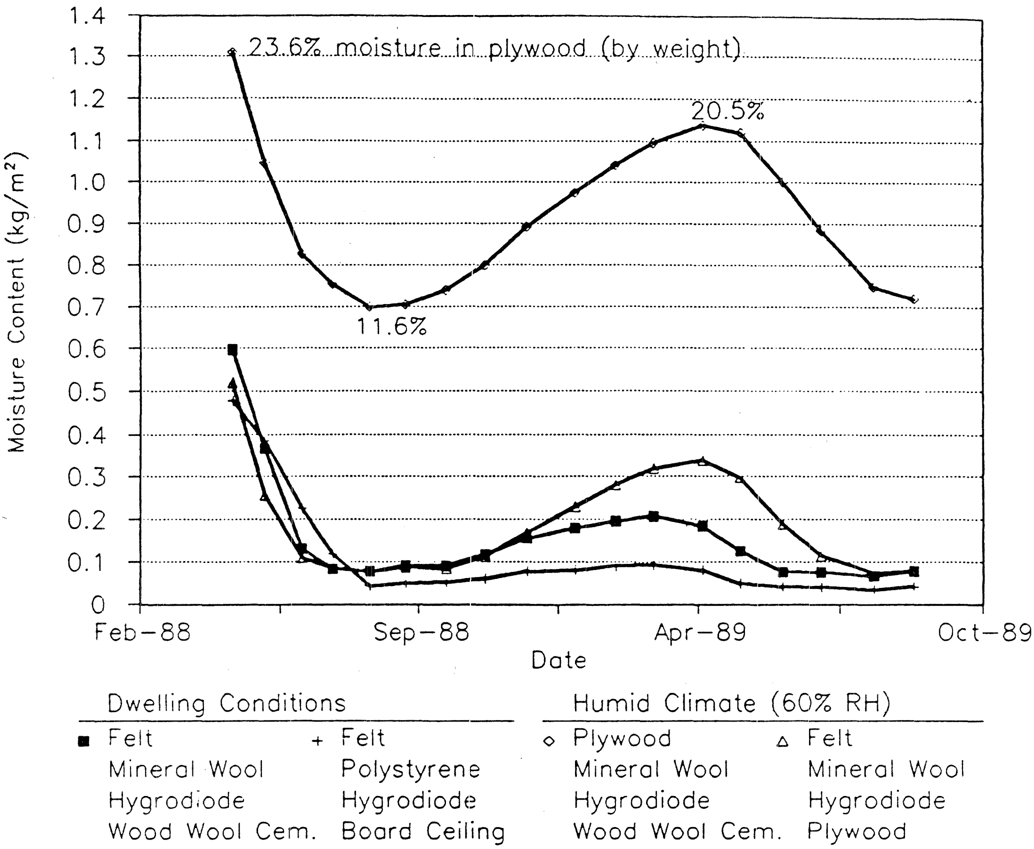


Figure 6. Moisture content in four of the roof test panels from the field test with the Hygrodiode ® vapour retarder.

Despite of the fact that the summer of 1988 was not a very sunny one, the added moisture was dried out of all four panels within the three to four summer months. There are some differences, however, in the drying rates and in the amount of moisture that was accumulated in the winter that followed.

The two warm deck panels with mineral wool had the same high drying rates. They dried out in only two months. The identity in drying rates between the two rooms may be explained by the relative humidity in the room with dwelling conditions to be close to 60% as the moisture content of the air is highest in the summer. The rate of moisture absorption in the winter was much higher, though, in the humid room than in the room with dwelling conditions. In this room, the panel gained more than 0.2 kg/m² while the gain was only half of this in the room with dwelling conditions. This moisture dried out again within the first months of the second summer.

The drying rate in the panel with expanded polystyrene insulation was approximately half of the drying rate in the similar panel with mineral wool. But this panel hardly gained any moisture in the winter. The primary cause for these observations is the smaller permeability of the polystyrene. Less moisture will migrate from the top of the roof through the insulation and condense on the Hygrodiode ® on a summer day when polystyrene is used. The moisture does however accumulate at the bottom of the insulation during summer and it will finally be dried out.

The moisture content in the panel with the cold plywood deck looks different because the plywood holds not only the moisture that was added initially, but also hygroscopic moisture which will never be dried out. The major concern is to get the moisture content in the plywood deck below 20% by mass as this is considered the critical limit for fungal attack. This corresponds to approximately 1.1 kg moisture per square meter roof, disregarding the moisture content in the other layers of the construction.

The moisture content in the plywood started from 23.6% and fell to 11.6% the first summer. The drying rate was slightly smaller for this panel than it was for the warm deck panels with the same permeable insulation. The reason is the hygroscopic capacity of the wood, i.e. the moisture is released at a vapour pressure less than saturation. This hygroscopically low vapour pressure is also responsible for the faster moisture gain in the winter. The moisture content ends up around the critical limit by the end of the winter when the temperature is still low, which means that the growing conditions for fungi are poor. The moisture dries out again in the next summer. It may be assumed that the moisture content in the plywood would have been safely below 20% if the roof panel had been installed over the room with dwelling conditions or had been installed hygroscopically dry.

Similar panels in the test had polyethylene as vapour retarder. Significant reductions in drying rates were observed in these panels. With this kind of vapour retarder, the potential for downward drying is practically eliminated. Thus, the moisture stays trapped between the two impermeable membranes.

Assuming specific effective water vapour permeabilities for the WPVP in its dry and wet state, som of the results shown above have been verified by a computer program, MATCH, for combined heat and moisture transfer in composite constructions (Pedersen, 1990).

CONCLUSION

The results from the test hut measurements of the seasonal moisture content in a number of different flat roof systems prove that the water permeable vapour retarder concept described in the paper is able to dry out moisture trapped in the roof system and make sure that the roof insulation will continue to stay dry. Using a conventional polyethylene vapour retarder hinders the possiblility for downward drying, and interstitial moisture will stay trapped in the roof cavity.

REFERENCES

Korsgaard, V., "Hygro Diode Membrane: A New Vapor Barrier", ASHRAE/DOE/BTECC Conference: "Thermal Performance of the Exterior Envelopes", Clearwater Beach, FL, USA December 2-5, 1985.

Pedersen, C.R., "Combined Heat and Moisture Transfer in Building Constructions", Ph.D. Thesis, Thermal Insulation Laboratory, Technical University of Denmark, 1990.

Korsgaard, V. and C.R. Pedersen, "Moisture Content and Distribution in Flat Roofs with Polyethylene or Hygro Diode Vapour Retarder": Proceedings of the 2nd symposium Building Physics in the Nordic Countries, Trondheim 1990.

COLD PIPING

Insulated cold piping (and sometimes ductwork) should receive special attention when exposed to ambient or non-conditioned air. Cold piping is frequently operated year-round. Thus, even with vapor retarder insulation jackets and vapor sealing of joints and fittings, moisture inevitably accumulates in the insulation, which eventually becomes saturated. This not only reduces the thermal resistance of the insulation, it also accelerates condensation on the jacket surface with consequent dripping of water and growth of mold and mildew. Depending on local conditions, these problems can arise in less than three years or can take as many as 20 or 30 years. Since there are no known solutions short of periodic insulation replacement, the design of the piping installation should provide convenient access for such replacement and means for drainage if dripping water would cause damage.

The preceding is a quotation from ASHRAE 1985 Fundamentals Handbook, chapter 21.19. In the 1989 edition, chapter 21.14 it is stated:

"Piping at temperatures below ambient is insulated to control heat gain and prevent condensation of moisture from the ambient air. Since piping is an absolute barrier to the passage of water vapor, the outer surface of the insulation must be covered by an impervious membrane or cover. This cover also helps protect the pipe against corrosion".

A new innovative concept is described in the paper which is a solution to the periodic insulation replacement.

THE WICK CONCEPT

The wick concept is shown in Figure 1. A wick fabric is wrapped around the pipe before the cylindrical hinge-and-lab insulation is placed around the pipe with the slot turned downwards. The fabric is extended through the slot and wrapped around the insulation. To reduce the amount of water vapor diffusing through the turbular insulation mantel, it should have a jacketing with a low permeance or a vapor retarder (VR) cover. Depending on the permeability of the jacket and the temperature and relative humidity of the ambient air, only a smaller part of the jacket needs to be covered by the wick fabric extending through the slot to give a sufficiently large area for evaporation of the absorbed water to prevent dripping.

The Wick Concept has been patent applied for.

PERFORMANCE TESTING

The wick-concept has been tested in the laboratory using a test rig shown in Figure 3.

The test rig consists of a steel pipe (outside diameter 27 mm) kept at 0°C by circulating water through a coaxial inner pipe so that the test-tubes can easily be drawn of the test rig to determine the increase or decrease of the total moisture content of the test-tubes by weighing at suitable intervals.

The PE test tubes (length 400 mm) have an inner diameter, a little larger than the outer diameter of the steel pipe so that the test tubes can easily be pulled off the test rig for weighing. The outer diameter of the tubular insulation is 75 mm.

Four different types of wick-fabric have been tested, which all perform well. In Figure 4 results are shown with a wick of non-woven Nylon (50 g/m²). The width of the nylon fabric adhered to the outer surface of the insulation is 50 mm, which gives an evaporation area for each test-tube of 20 000 mm². Depending on the permeability of the VR-jacketing and the relative humidity of the ambient air, the evaporation area necessary is much less.

Two of the test-tubes have glasswool insulation (ρ = 70 kg/m³) dry weight 0.098 kg.

Two of the test-tubes have Rockwool insulation (ρ = 140 kg/m³) dry weight 0.194 kg.

One of each insulation type is without any surface finish. One of each has an aluminum foil VR cover, with a 10 mm longitudinal slot in the top to accellerate moisture formation on the test-tube.

The test-rig is placed in a room with a constant temperature of 21°C and 54% rh.

The nylon wick was slightly moistened before it was wrapped round the pipe.

The development of the moisture content versus time of the four test-tubes is shown in Figure 4.

The moisture content of the glasswool test-tube without any surface finish is increasing slightly over the first 30 days, stabilizing with a moisture content of app. 30 g corresponding to 30% by weight or 2% by volume.

The moisture content of the Rockwool test-tube without any surface finish is stabilizing after app. 8 days with a moisture content of 10 g corresponding to 5% by weight or 0.7% by volume. The moisture content of the glasswool test-tube and the Rockwool test-tube with Al-jacket is decreasing slightly the first day. This is due to drying of the slightly wetted wick. After that the weight is only increasing very little, stabilizing at the starting weight.

The larger fluctuations of the moisture content of the glasswool test-tubes are due to a much larger hygroscopic capacity of the glasswool compared with Rockwool. A factor of app. 10 has been determined.

After 48 days, point A on the time axis, the extended part of the wick fabric is covered by adhesive tape to prevent evaporation, and hence the drying effect of the wick is stopped. This is clearly seen from the steep increase of the weight of the test tubes. The slope is steepest for the test tubes without aluminum foil cover as could be expected. On the other hand, one should expect that the slope for the Rockwool and glasswool insulation should be app. the same as the diffusivity of the two insulation materials is app. the same. For the test tubes with aluminum cover, this is also the case for the first 7 day period. In the second 7 day period, the slope for the Rockwool test tube decreased, but increased for the glasswool test tube. Sofar we have no certain explanation for this deviation. A great part may be due to the great difference in hygroscopicity, and a minor part to the difference in density.

After the two 7 day periods, point B on the time axis, the adhesive tape was removed so that evaporation and hence drying could start again, as can be seen from the figure.

At point C, the test tubes were separated, and the moisture content in the tubular insulation and the wick was determined gravimetrically. The moisture content in the Rockwool without VR was 3.4 g and with VR 0.2 g. For Glasswool without VR the moisture content was 25 g, and with VR 2.6 g.

In the three cases all the moisture was concentrated in the wick, and the insulation was dry. Most of the 25 g in the Glasswool test-tube was in the wick, a minor part was in the app. 1 mm thick gasswool layer in direct contact with the wick. The reason for this is possibly that the water repellant resin in the glasswool inner layer is destroyed by high temperatures during the manufacturing process.

Figure 4 clearly shows that the Wick concept is able to keep the insulation dry even without a jacketing of a low permeance.

WICK FABRIC

The hygroscopic qualities of the hydrophilic wick fabric used has been measured.

The wick fabric is as mentioned a non-woven Nylon weighing 50 g/m². The capillary suction height is 40 mm. The suction capacity of a slip 10 mm wide is 70 g/h. The rate of evaporation has been measured to be 40 g/m²h in still air at 21°C, 54% rh.

BELOW FREEZING PIPING

If the temperature of the pipe is below 32°F (0°C), the condensed vapor will freeze and cannot be removed from the pipe surface by wicking action.

To be able to utilize the wick concept, Figure 5, the insulation must be applied in two layers. The thicknesses of the two layers are determined so that the temperature of the layer of separation is a few degrees over the freezing point.

A vapor retarder is wrapped around the first insulation layer, and then a wick fabric is wrapped around and extended through the slot in the second insulation layer and adhered to the outer vapor retarder.

As the vapor retarder on the inner insulation layer is not perfectly vapor proof, a minor amount of vapor will pass through over the years and form ice on the pipe surface. Most freezing plants are shut down for maintenance with intervals of one or more years, and the ice will melt. If the wick concept is also applied to the pipe surface, the moisture will be removed and the inner insulation will dry out.

LONG TERM TESTING

A test rig for long term testing of a pipe system including horizontal and vertical pipes, fittings, valves and flanges has been established, Figure 6.

Moisture condensing on the fittings, etc. is transferred to the wick in the insulation of the straight pipes by stripes of a wick-fabric wrapped around the fittings, etc., as can be seen in the figure, where some straight pipe insulation still has to be installed. After a couple of months, the insulation will be dismantled, and the moisture content will be determined by gravimetric analyses.

CONCLUSION

Accellerated laboratory performance testing has shown that it is possible to prevent moisture accumulation in cold pipe insulation by means of a concept utilizing the wicking action of a hydrophilic fabric to remove condensed moisture from the pipe surface through a slot in the insulation to the outer surface of the insulation from where it can evaporate into the ambient air.

REFERENCES

ASHRAE, Fundamentals Handbook.

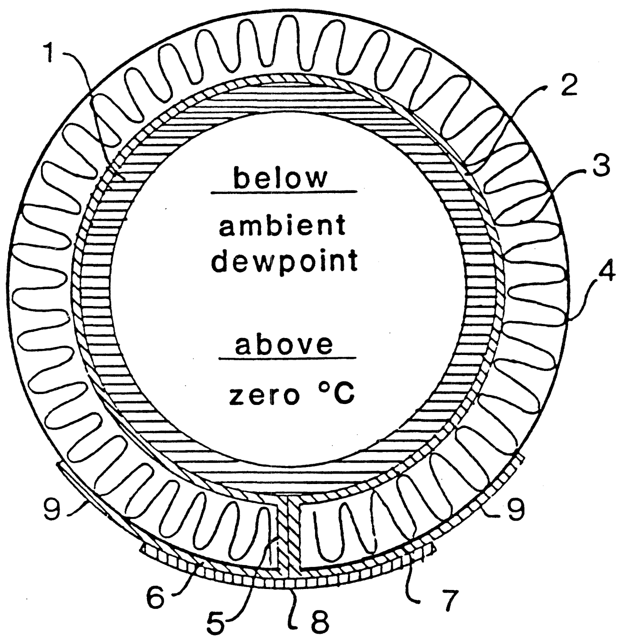


Figure 1. Pipe (1) with tubular insulation (3) with an impervious jacketing (4) and a wrapped around wick (2) extending through the slot in the insulation (5) with an evaporation area (9). Adhesive tape (8) to close the slot.

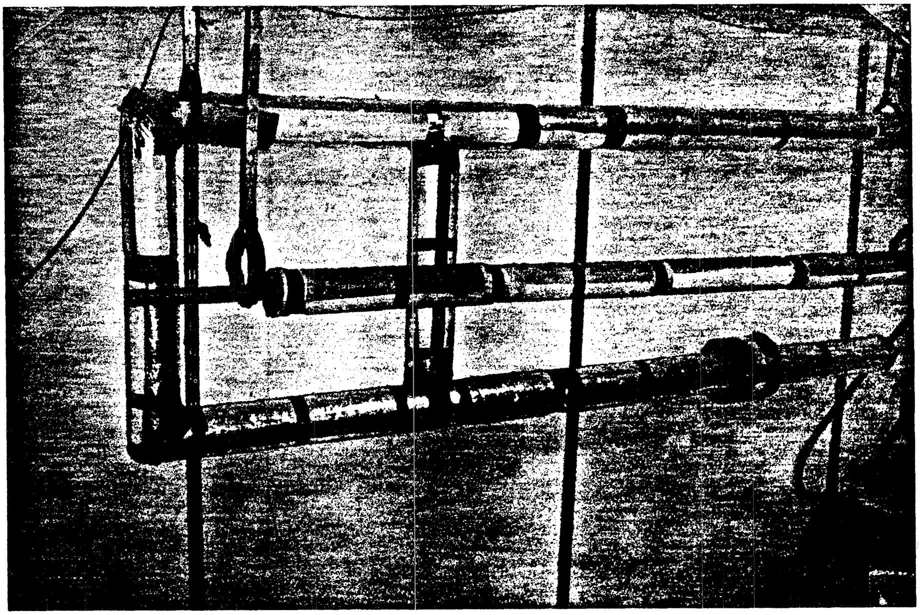


Figure 2. Photo of test rigs.

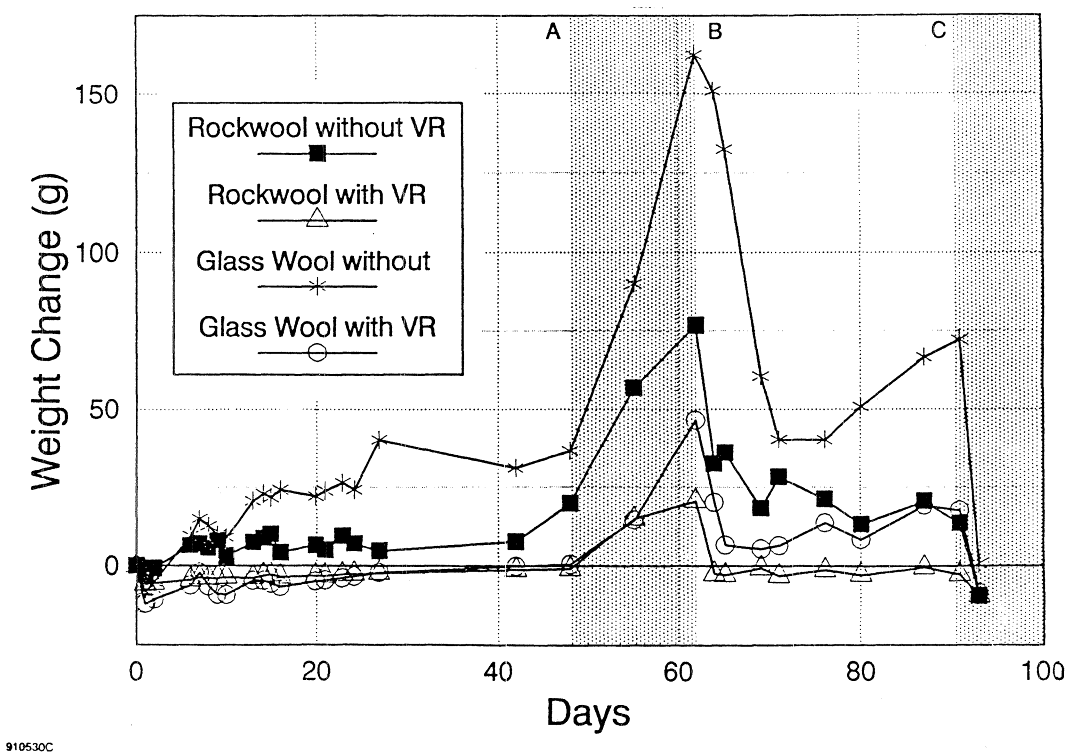


Figure 3. Development of moisture content of four test-tubes with the wick-system installed.

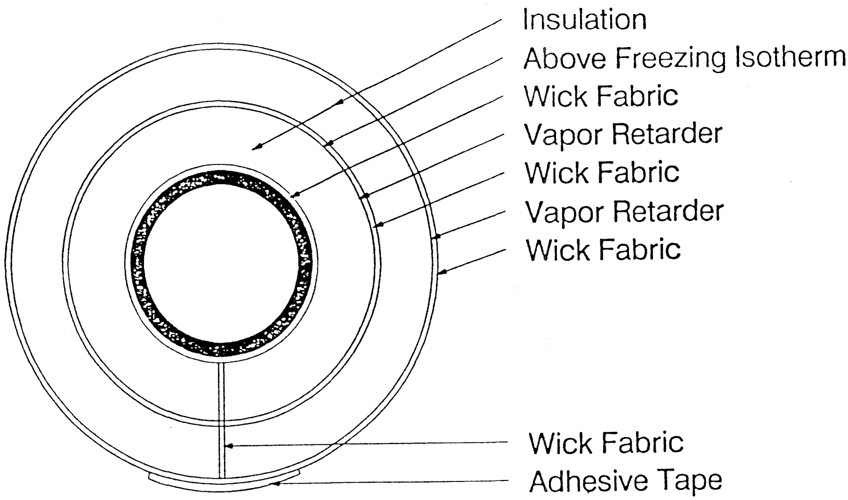


Figure 4. The wick-concept applied to a pipe at below freezing temperature.

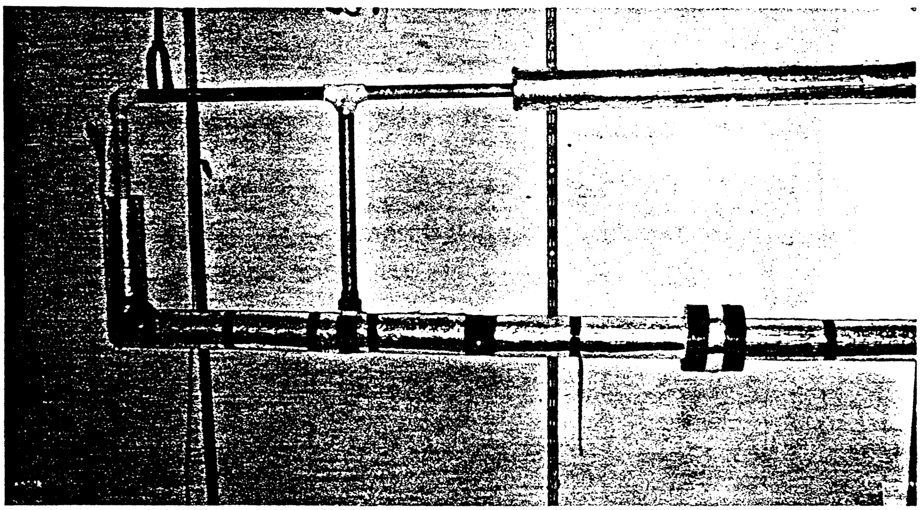


Figure 5. Photo of long term test rig.

Per-Ingvar Sandberg
Swedish National Testing and Research Institute
Sweden

Can modern moisture research predict ordinary moisture problems?

INTRODUCTION

The question in the title is plain and the answer is equally plain - "No !" or perhaps "No, not always !". The situation is that we in a number of cases are not in a position to predict moisture problems and that many moisture problems occur quite unexpected. If we look at our position from an other angle we can also note, that we can not always explain why moisture problems have *not* occured in a given situation.

On the other hand it is quite clear that *if* we were using the existing knowledge in a systematical way, we could make very good predictions even if there are shortcomings and gaps in our knowledge. Considering this the answer could as well be "Yes, mostly !".

LACK OF KNOWLEDGE

The reason for the "No" is that we still after many years of research and efforts in several parts of the world have considerable lacks of knowledge in at least three fields:

Prediction of moisture content

Moisture transfer models. The physical reality is often very complex and the models we use have shortcomings and do not always describe the reality in an adequate way. Interaction between materials, coupled effects of heat and moisture or heat and air flow are difficult to deal with.

Material properties. We still lack a lot of necessary data for many materials. Effects of temperature level and temperature gradient on moisture transfer are examples of areas where knowledge is more or less non-existent. Dispersion in the production and consequently also in moisture characteristics is an other area where much more information should be welcome. Today we have at best one single value and no information on the statistical distribution.

Boundary conditions.

We do not have enough information on all the relevant **climatic parameters** such as temperature, humidity, radiation, wind, rain etc. Intensities, duration curves and combinations of several parameters are all necessary for a good prediction. Climatic data are normally taken at a meteorological station and we have to modify them to be valid at the building in question.

Criteria for allowed moisture contents in different materials.

How much moisture can be allowed before problems occur? Problems like **dimensional changes, corrosion, frost damage and biological deterioration (mould and rot)** could be expected for "wrong" moisture conditions.

An other question is the effect of **combination of moisture with temperature and in many cases time**. Dimensional change is a question of moisture content only, frost damage depends on a combination of moisture and temperature and biological deterioration is dependent of the combined effects of moisture - temperature - time.

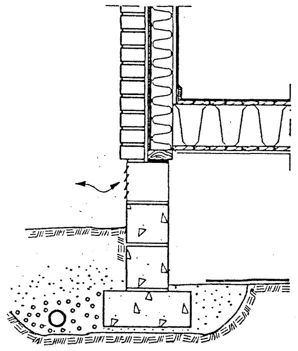
SHORTCOMINGS IN INFORMATION AND OVER-VIEW

Even if we had all this information, we still would have to expect moisture problems for several reasons. Shortcomings in training and information have the effects that many persons involved in the building process (from planning to construction and use) do not have adequate knowledge to always do the right things and take the best decisions. There is a gap between researchers at the research frontier and the user of his results. Both the researcher and the receiver of information should be blamed for this; the researcher should spend more time to disseminate his knowledge in a pedagogical and useful way and the practicing engineer must feel a responsibility to look for and use as up-to-date information as possible.

Another problem is that today - at least in our country - no-one has an overview or feels the responsibility to have an overview of the whole building process. Many things may happen to a construction product in the chain: **production - transport - storage at the building site - handling during construction - inspection - end-use**. Ignorance or lack of concern for one or more of these links is often a reason for moisture problems.

EXAMPLE: CRAWL SPACE

Let us as an example to illustrate the current situation try to predict the risk for moisture problems in a conventional crawl space, ventilated with outside air, see fig below.



The crucial condition in this construction is the realtive humidity in the organic materials (wood and wood-fibre board) which are in contact with the crawl space atmosphere. The problem we can anticipate is mould or in worst cases rot.

The relative humidity at the surface of the materials is a result of the moisture balance between the material and the air in the crawl space. Consequently we need to deal with material properties, boundary conditions and criteria for allowed moisture contents, all areas, where we have shortcomings in knowledge as mentioned above.

Material properties: Moisture transfer coefficients and isotherm for wood and wood-based products, especially for high moisture contents, effects of impregnation or surface treatments?

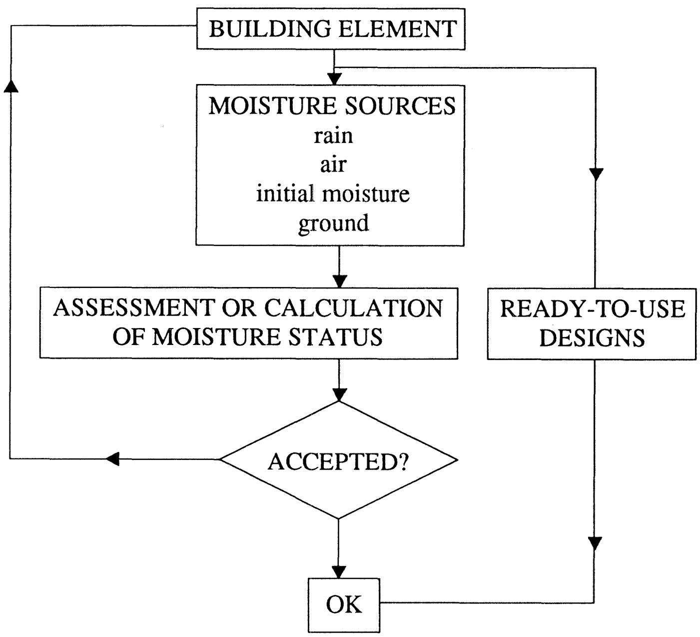
Boundary conditions: Temperatures of the air and the surfaces in the crawl space? Air pressures around the building, wind exposition? Ventilation openings - will they be according to drawings, will they be blocked by trees or flower beds etc?

Criteria for allowed moisture contents: We know that the relative humidity for periods will go above critical values, but what is the risk for mould at different temperatures and duration of exposure to critical conditions?

IS THE CONCEPT OF MOISTURE DESIGN A SOLUTION TO THE PROBLEM?

Maybe I have given a too pessimistic view of the current situation. After all, we have made a lot of progress and we can adequately handle a number of problems. Still more safety against moisture problems would be gained if the existing knowledge were used in a systematic and conscious way. Here in Lund we have tried to develop a systematic design process to deal with risks of moisture problems.

Moisture design is concerned with the measures in the building process intended to ensure that the finished building does not suffer from damage or problems caused directly or indirectly by moisture. There are several parallels that can be drawn with, for example, static structural design. The figure below illustrates the elements involved in the work of moisture design.

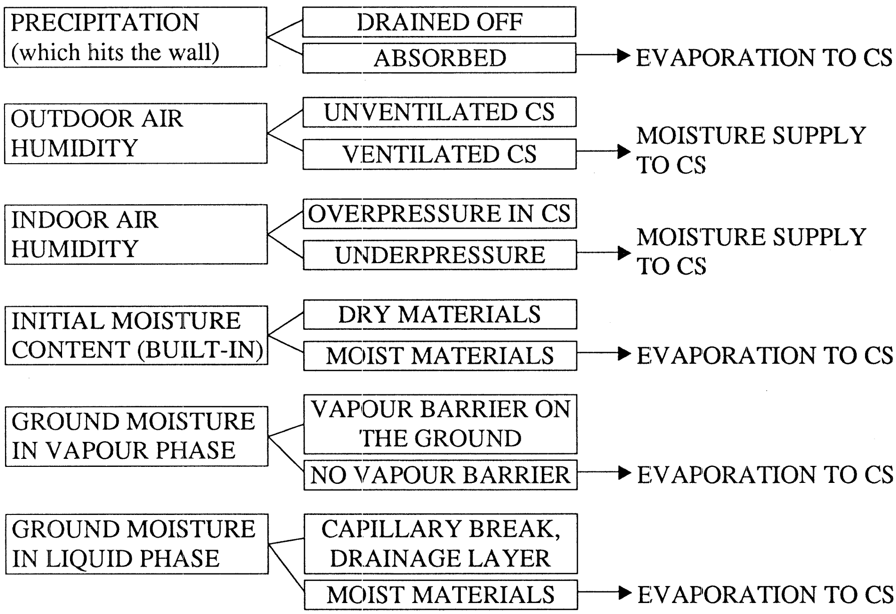


One way is to use ready-to-use designs, which have been proven satisfactory. Otherwise it is necessary to consider and sum the effects on the moisture conditions of all the relevant moisture sources. If the moisture conditions can be accepted, considering relevant criteria, the risk of moisture problems should be small - if not, changes in the design of the building element must be considered.

Safety factors and safety philosophy are important aspects in the moisture design process. In the long term, attempts should be made to ensure that moisture conditions are not expressed simply as induvidual values but as the probabilities of certain moisture states occuring. This includes allowing for variations in climate, material characteristics, user habits etc. This probability can then be weighed against the risk of certain damage or problems occurring, thus constituting a risk analysis.

MOISTURE DESIGN FOR CRAWL SPACE; EXAMPLE

To give an idea of the systematic way to deal with all the moisture sources, the supply of moisture to the crawl space is taken as an example. The effect of each moisture source is considered. CS = crawl space.



Lars-Erik Harderup
Dept. of Building Physics, Lund University
Sweden

CONCRETE SLAB ON THE GROUND AND MOISTURE CONTROL - VERIFICATION OF SOME METHODS TO IMPROVE THE MOISTURE CONDITIONS IN THE FOUNDATION

PREFACE

The summery in this paper is obtained from a report by L-E Harderup, (1991b). In this paper some results from field measurements performed within the project will be illustrated by a few examples. Further information about the field measurements and the numerical methods is to be found in the report mentioned above.

SUMMARY

The final report deals with different types of repair methods for concrete slab on the ground damaged by moisture. Many of the available methods involve some kind of mechanical ventilation of the foundation. The basic principle for all these systems is the same. By establishing air movement through an air-permeable layer below or above the concrete slab, the flowing air can absorb moisture from surrounding materials. When the air has passed through the layer, it is transported out of, and away from, the foundation. Three methods of this type have been thoroughly examined by way of field measurements in single-unit dwellings.

In one of the dwellings, a system for one-dimensional air flow below the concrete slab was investigated. Indoor air was pumped into the foundation at one gable and sucked out from the foundation at the opposing gable. The air-permeable layer in this building was made of expanded clay aggregate with a high capillary rise. One year after the mechanical ventilation of the foundation started, the concrete slab was much dryer than before the system was applied. Other measurements showed that there was only a minor decrease in moisture content mass by mass in the sills. The temperature in the foundation below the concrete slab increased, near the inlet gable. The drying-out process of the foundation showed that the air flow was not one-dimensional.

A system with an air gap between the concrete slab and a vapour barrier was investigated by means of field measurements for a year and a half. Indoor air was sucked into the foundation through specially designed skirting-boards and then transported to the centre of the building, where it was sucked out through a ventilated skirting-board. The air flow in the investigated system was supposed to be one-dimensional. Negative pressure would prevent odours from the floor from entering the building. The measurements showed that the humidity by volume in the ventilated air gap decreased immediately once the mechanical ventilation system was set in motion. The indoor climate improved, too. However, different types of measurements showed that indoor and outdoor air leaked into the system. With air leaking into the system, the air flow cannot be one-dimensional.

A mechanically ventilated joist-floor construction has also been investigated by way of field measurements. The measurements in this building were being taken for two and a half years. A negative pressure was obtained in the joist floor by installing a centrally-placed

exhaust-air fan. The fan was connected to the joist floor. Inlets from the inside air to the joist floor were placed near the outer wall corners. This type of system provides a two-dimensional air flow in the foundation. Measurements in the joist floor showed that the air dried out the joists and other wooden material in the floor. The upper part of the concrete slab was dried out by the system, too. The quality of the indoor air was also improved. However, there was considerable air leakage both from indoor and outdoor air. Air leakage from the outside in winter cooled the concrete slab below the external sills and near the external walls.

The general conclusion drawn from the field measurements is that it is very important to perform extensive measurements in the building before any repair actions are carried out. It also seems very difficult to avoid air leakage between the ventilated layer on the one hand and outdoor and indoor air on the other.

Three transient numerical models have been developed within the project. All three models can be used to predict temperatures in different parts of mechanically-ventilated foundations. One of the models can also be used to predict moisture conditions in the ventilated layer.

Superposition and scaling were applied in order to demonstrate a method of determining the temperature distribution in a ventilated layer on the basis of diagrams and simple manual calculations. The influence on the temperature in the ventilated air gap of variations in air-flow rate, thermal conductance below and above the air gap, periodic outdoor temperature and increased inlet temperature can be analysed by means of this method.

BACKGROUND

All buildings are affected by moisture. Water can be transported to the building in many different ways. In this paper the water supply to concrete slabs on the ground is of special interest.

Many Swedish buildings suffer from mould growth and odours caused by moisture uptake, which in a majority of buildings originates from the ground. Statistics from investigations in a lot of Swedish buildings show that concrete slab on the ground is the most common foundation type in buildings damaged by moisture.

In the last decade a lot of methods have been developed in order to repair concrete slabs on the ground, damaged by moisture. For this reason it is of great importance to study the effectiveness of such methods in different situations. A number of reports, papers and leaflets have been published which describe how different repair methods have been used in different situations.

In most of the published reports about the subject, there is no detailed information about specific cases, and furthermore there is little or no information about the moisture conditions in the investigated buildings before and after the repair actions were carried out. In some cases many different repair methods have been carried out at the same time. This makes it very difficult to investigate which of the methods has been successful.

Swedish authorities are worried about the widespread problem with "sick buildings" and are looking for effective repair methods in order to improve the indoor climate.

The goal and endeavour of this project have been to investigate the effectiveness of different repair methods for concrete slabs on the ground, damaged by moisture. This paper deals with methods that involve some form of mechanical ventilation of the foundation. The main purpose of the ventilation is to prevent or diminish the moisture supply to the concrete slab and its connections to the walls. Other repair methods that have been investigated within this project have been published in separate papers and documents; see for example L-E Harderup, (1987) and L-E Harderup, (1990).

TYPES OF FOUNDATIONS

Foundations can be designed in three different ways. Slab on the ground, crawl-space and cellar. Figure 1 show two buildings with foundation of the type slab on the ground. In Sweden the slab is usually made of concrete and the edges are made of either reinforced concrete or blocks of expanded clay aggregate. The thermal insulation is placed above or below the concrete. Thermal insulation below the concrete usually consists of mineral wool, cellular plastic or expanded clay aggregate. If the thermal insulation is placed above the concrete it is usually made of mineral wool or cellular plastic. In all of the cases mentioned the insulation may cover the whole of the slab or part of it. In Sweden with its severe climate, at least in the northern part of the country, the thermal insulation is rather thick near the edges. When the distance to the edges increases the Swedish building Code allows you to decrease the thickness of the thermal insulation. The heat losses to the ground is not always a reason for insulating the central region of a concrete slab. However, to avoid moisture problems originating from the ground it is recommended to have thermal insulation below the entire concrete slab. This is especially important in Sweden, since there is no vapour barrier below the concrete. To avoid moisture problems in new buildings, certain design rules must be fulfilled. For concrete slab on the ground this type of information can be found in Nilsson, (1977), Fagerlund, (1980) and Nilsson, (1983).

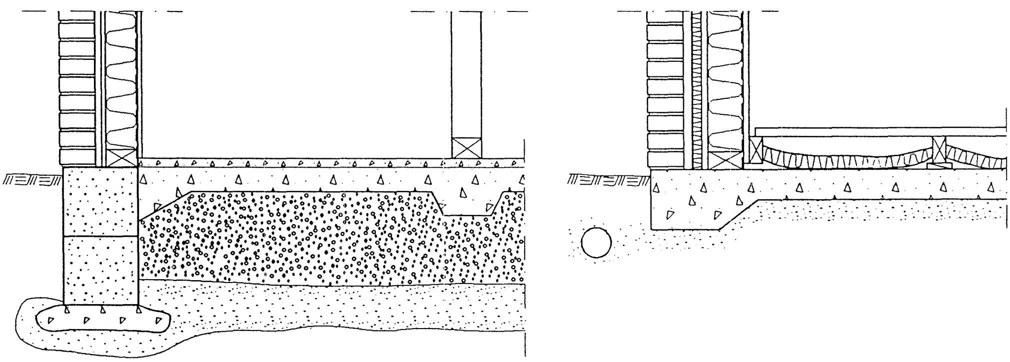


Figure 1: Buildings with foundation of the type slab on the ground.

PROBLEMS AND COMPLICATIONS

In Swedish buildings founded with basement or concrete slab on the ground there is usually a capillary breaking layer below the concrete slab which should prevent capillary rising water from the ground from coming in direct contact with the concrete. If the capillary breaking layer has insufficient quality, or if the layer is too thin, the concrete can be moistened by capillary rising water from the ground. If the capillary breaking layer below the building is effective, water can still be transported to the concrete slab by diffusion from the ground, especially if the temperature difference between concrete slab and soil is small. In some situations this water supply is big enough to cause severe problems in the upper part of the foundation of the building.

Water can also be transported to the concrete slab in other ways. Driving rain can penetrate the facade of the building and be transported to the outer wall sills. Thawing snow can moisten the connection between the foundation wall and the lower part of the outer wall. A high moisture supply to the inside air, combined with a low air change rate, can result in moisture problems in the foundation. If there are vertical air gaps through a thermal insulation placed above the concrete, the humid indoor air might condense on the cold surface of the concrete. Leaking pipes embedded in the concrete or in the thermal insulation above the concrete slab can also cause severe moisture problems. Water can be transported into the concrete if the joint water level is high below the building.

Mechanical ventilation of an air permeable layer in a foundation is used to prevent moisture problems originating from the ground. This ventilation technique is a complicated process to simulate. The relative humidity in the air varies during the year. The moisture supply to the inside air varies. The permeability in the ventilated layer varies. Unexpected air leakage diminishes the effectiveness of the system. Finally it is difficult to know the size of the moisture supply to the concrete slab from the ground.

For many flooring materials there is a critical relative humidity which may not be exceeded, if the material is going to function sufficiently for a long period of time. Mould growth is also dependent for growth on a high relative humidity. As the relative humidity depends on the temperature at a certain humidity by volume it is also important to investigate the thermal process in the ground. This is also a complicated process. The temperature field is three-dimensional and time varying. The thermal process in the ground has been thoroughly examined by Hagentoft, (1988).

BASIC CONFIGURATIONS TO BE ANALYZED

Figure 2 to 4 show the three basic configurations to be analyzed in this paper. In all three cases indoor air is sucked or pumped into the foundation. As the air passes through the foundation it is moistened by water from the concrete and from the soil. If the systems function properly they will remove the moisture supply from the ground and lower the moisture content in the concrete. To decrease the air flow rate and avoid condensation or mould problems in the foundation, the indoor air should be as dry as possible. The ventilated layer below the concrete can be made of any material, as long as it is sufficiently air permeable.

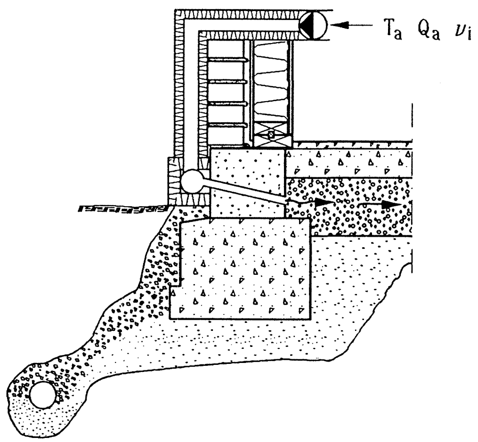


Figure 2: Building with an air permeable layer below the concrete slab.

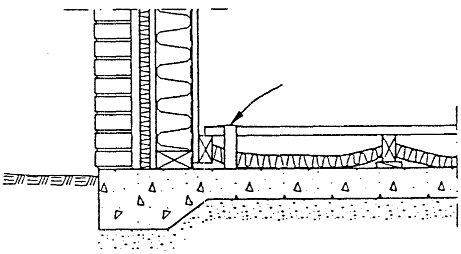


Figure 3: Building with a ventilated joist floor construction on a concrete slab.

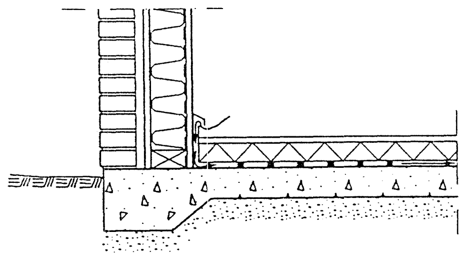


Figure 4: Building with a ventilated vapour barrier above the concrete slab.

The field measurements deal with temperature and moisture conditions in the foundations mentioned above. The main purpose was to investigate the concrete slab. Since odours and mould growth primarily originate from wood and other organic material in the foundation it was also important to investigate external and interior sills. The climate of the indoor and outdoor air, and sometimes the precipitation and the joint water levels, are also important to know when the measurements are evaluated.

SOME RESULTS FROM FIELD MEASUREMENTS

Extensive measurements of temperature and moisture conditions have been carried out in a few buildings with mechanical ventilation of the foundation. Parallel to the field measurements three numerical models have been developed to calculate and predict temperatures and moisture conditions in the ventilated layer. From the measurements and the calculations it is possible to draw some general experience from mechanical ventilation of the foundation as a way to eliminate moisture problems originating from the ground.

Figure 2 showed a system designed for one-dimensional ventilation of the foundation, below the concrete slab. Indoor air was pumped into the foundation at one gable and sucked out from the foundation at the opposing gable. One year after the mechanical ventilation of the foundation started, the concrete slab was much dryer than before the system was applied. Other measurements showed that there was only a minor decrease in moisture content mass by mass in the sills. However, measurements and calculations showed that the system did not work as expected, see Figure 5. The air flow in the foundation is not one-dimensional. If the air permeability in the expanded-clay-aggregate layer is low, air is pressed out at the foundation walls below the facades near the inlet gable, and sucked in through the foundation walls or from the inside air at the facades near the outlet gable. This means that there was no or little air flow from one gable to the other when the system was started.

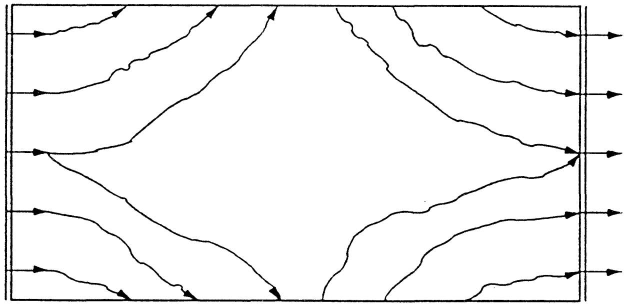


Figure 5: Possible air flow pattern in the ventilated foundation if the air permeability is low in the ventilated expanded-clay-aggregate layer below the concrete slab.

Another example of results from field measurements are shown in Figure 6. This system is of the type described by Figure 4. Indoor air was sucked into the foundation through specially designed skirting-boards and then transported to the centre of the building, where it was sucked out through a ventilated skirting-board. Negative pressure would prevent odours from the floor from entering the building. Figure 6 shows mean value of the humidities by volume in the ventilated floor, where the air is supposed to flow one-dimensionally from left to right. From Figure 6 it can be seen that in November 1987 the humidity by volume in the ventilated floor along measuring line B first increases, and then decreases after about 2.5 m. This indicates that a leakage of air from the indoor air occurs.

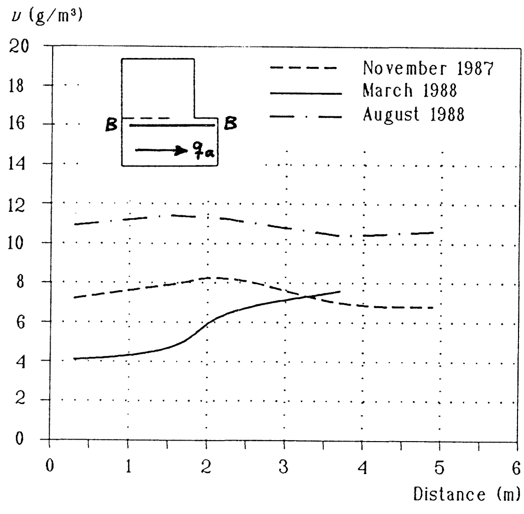


Figure 6: Mean value of humidity by volume along measurement line B in the ventilated floor.

From the measurements made in March 1988 it can be seen that the shape of curve B has altered. In this measurement the humidity by volume increases in the neighbourhood of the exhaust side. Since the householder was informed of the leakage after the previous measurement, the result indicate that the sealing, between the floor and the wall, has been improved near the outlet from the floor. The sudden increase in humidity by volume near the outlet also indicates that the air flow is rather poor in this part of the floor. The August measurements show that the humidity by volume once again falls in the neighbourhood of the ventilated skirting-board on the exhaust side, (to the right in Figure 6). The results indicate that leakage from the indoor still occurs despite that the system was partly rebuilt and sealed during the spring of 1988. The flat appearance of the humidity by volume curves in August 1988 depend on the fact that the air flow through the fan was higher than under the previous measurement periods, and that the pressure drop in the system was reduced after the system was rebuilt.

Figure 7 show results from the building described in Figure 3. A negative pressure was obtained in the joist floor by installing a centrally-placed exhaust-air fan. The fan was connected to the joist floor. Inlets from the inside air to the joist floor were placed near the outer wall corners. This type of system provides a two-dimensional air flow in the foundation. Results from measurements in this building are exemplified by the relative humidities in the joists in the floor. Figure 7 show the results from one of the bedrooms. These measurements were performed on three different occasions, November 1984, January 1985 and June 1987. The system was started in December 1984.

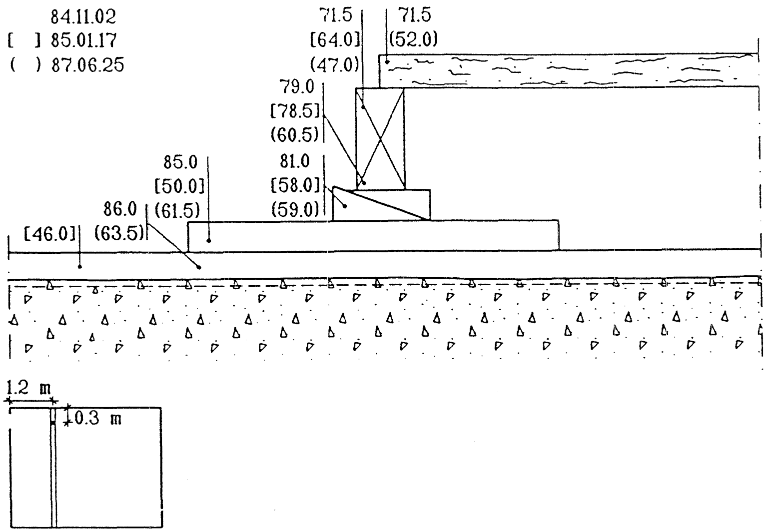


Figure 7: Relative humidities in the joist floor in bedroom 2 in November 1984, January 1985 and June 1987.

As an example we can study the upper part of the joist. The relative humidity decreased from $\simeq$72% in november 1984 to 64% in January 1985. In June 1987 the relative humidity was still lower, or 47%. In the partly embedded batten the relative humidity was 86%, 46% and 64% respectively. Results from Figure 7 and other measurements in the joist floor showed that the air dried out the joists and other wooden material in the floor. The upper part of the concrete slab was dried out by the system, too. The quality of the indoor air was also improved.

GENERAL EXPERIENCE DRAWN FROM THE FIELD MEASUREMENTS

The field measurements mentioned in this paper were carried out in three buildings. In one building a system for mechanical ventilation below the concrete slab was investigated. Two systems for mechanical ventilation above the concrete slab were examined, too. In one of these buildings, the measurements concerned a system with mechanical ventilation between the concrete slab and a vapour barrier. A system with two-dimensional air flow in a joist floor was investigated in the third building.

As the measurements were only carried out in three buildings, the results cannot be put to use in order to determine whether the measured results are representative of the investigated repair methods. However, the measurements are useful when it comes to identifying the kinds of investigation that are necessary to perform before a certain repair method is applied.

A general experience drawn from the field measurements is that it is very difficult to construct a system which provides mechanical ventilation of the foundation without incurring air leakage. Therefore, designers of this type of system should supply detailed construction drawings and training to the people who install the systems. After installation, it is necessary to check the system regularly.

In some buildings with mechanical ventilation of the foundation, the system is *working because of the air leakage*. For example, air leakage from outdoors between the concrete slab and the sills will prevent the moisture supply from the ground from moistening the sills. A negative consequence of this form of air leakage is that a temperature decrease will occur below the external sills and near the foundation walls.

The concrete slab is often reinforced beneath the structural interior wall in the middle of a building. It is also common for the thermal insulation and the capillary-breaking layer to be thinner beneath this type of reinforcement. Consequently, if a system for mechanical ventilation below the concrete slab is used, it is difficult to ventilate this area efficiently. As the concrete is thicker below a structural interior wall, the drying-out process is slower here than in the remainder of the concrete slab. Furthermore, the structural interior wall may be partly embedded in the concrete. These structural problems will extend the drying-out process of the interior sills.

If the foundation walls are in capillary contact with the joint water, it may be difficult to prevent moisture uptake to the external sills by mechanical ventilation of the foundation (with an airtight system).

When a mechanical system is connected to an existing floor, or to an air-permeable layer below the concrete slab, it is almost impossible to know for sure whether all parts of the foundation are efficiently ventilated.

REFERENCES

1. Fagerlund, G. Concrete slabs on the ground without moisture damages, (in Swedish). BPA Byggproduktion AB - Svenska Riksbyggen, Sweden, Handling nr 32, 1980.

2. Hagentoft, C-E. Heat loss to the ground from a building. Slab on the ground and cellar. Dept. of Building Technology, University of Lund, Box 118, S-221 00 Lund, Sweden. CODEN LUTVDG(TVBH-1004), 1988.

3. Hagentoft, Harderup. Coupled air flow and heat conduction model for mechanically ventilated foundations. Contribution to the AIVC conference in Dipoli, Finland, September 25-28, 1989. Dept. of Building Technology, University of Lund, Box 118, S-221 00 Lund, Sweden. CODEN LUTVDG(TVBH-7115), 1989.

4. Harderup, L-E. Activities at The Moisture Research Group 1984-87, pages 13-25 and 95-103, (in Swedish). Dept. of Building Science, University of Lund, Box 118, S-221 00 Lund, Sweden. Fuktgruppen informerar 1987:1, 1987a.

5. Harderup, Claesson, Hagentoft. Prevention of moisture damage by ventilation of the foundation. Contribution to the CIB-W40 conference in Borås, Sweden, September 1-3 1987 and to the AIVC conference in Überlingen, West Germany, 21-24 September 1987b.

6. Harderup, L-E. Functional control of a Jape Ventilagegolv. Preliminary results, (in Swedish). Dept. of Building Technology, University of Lund, Box 118, S-221 00 Lund, Sweden. CODEN LUTVDG(TVBH-7105), 1987c.

7. Harderup, L-E. Moisture problems in a building with a floating floor. Field measurements and suggestions of action, (in Swedish). Swedish Council for Building Research. R94:1990.

8. Harderup, L-E. Moisture in buildings and materials. Research 1987-90, The Moisture Research Group, (in Swedish). Swedish Council for Building Research. R7:1991a.

9. Harderup, L-E. Concrete slab on the ground and moisture control. Verification of some methods to improve the moisture conditions in the foundation. Dept. of Building Technology, University of Lund, Box 118, S-221 00 Lund, Sweden. CODEN LUTVDG(TVBH-1005), 1991b.

10. Nilsson, L-O. Moisture problems at concrete floors, (in Swedish). Dept. of Building Technology, University of Lund, Box 118, S-221 00 Lund, Sweden. CODEN LUTVDG (TVBM-3002), 1977.

11. Nilsson, L-O. Design of moisture protection for concrete slabs on the ground. Present knowledge and examples of solution, (in Swedish). Swedish Council for Building Research. R90:1983.

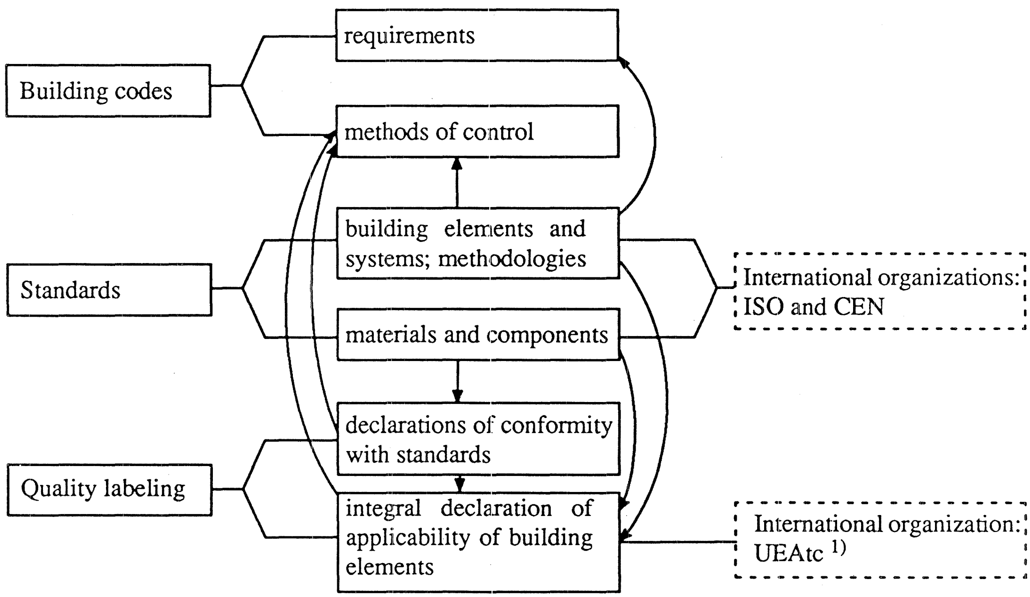
Eltjo Tammes
The Netherlands

National and international standardization in the field of thermal insulation

The concepts of standardization and thermal insulation

The title of this presentation suggests that it should be clear to everybody what is meant by the expressions "standardization" and "thermal insulation". Yet, giving a satisfactory description of these concepts is not so easy as one would expect of first sight. Stating that standardization is the preparation of documents to be issued by ISO, CEN or any national memberbody of these organizations may be technically correct but such a statement is as unsatisfactory as it is cool and clinical.
It may very well be possible to agree on a general definition but is must be feared that such a definition is more of philosophical than of practical significance.

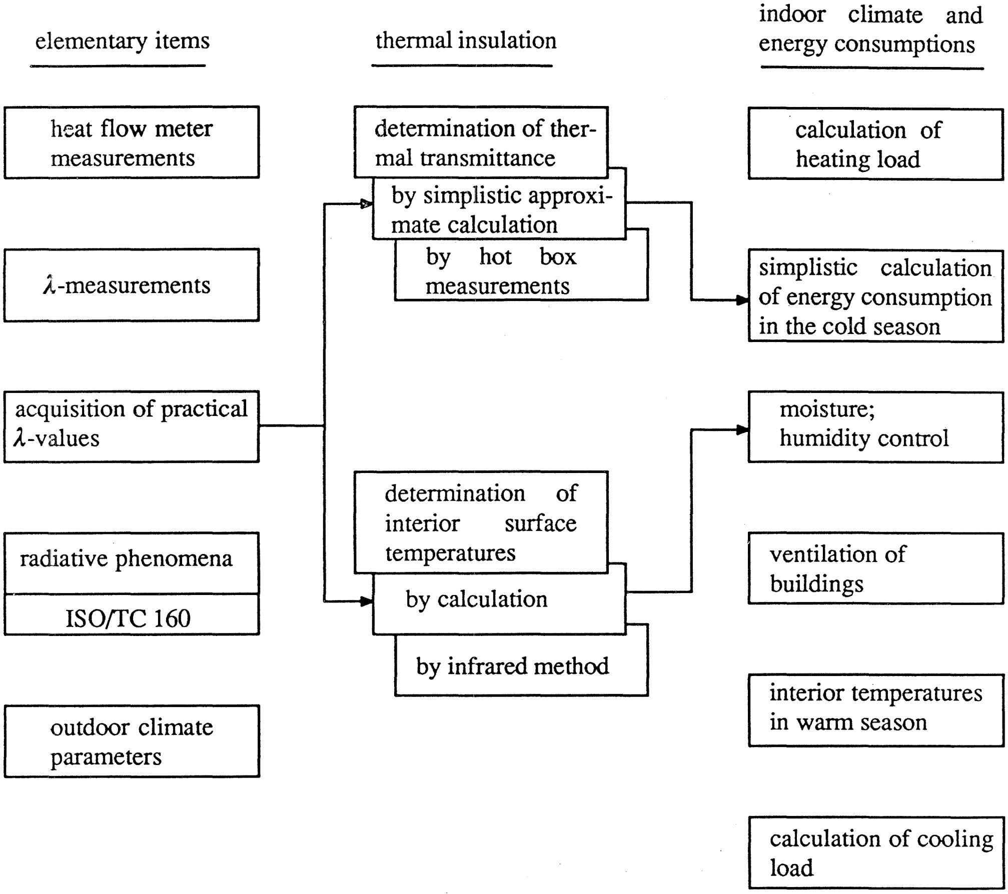
Restricting ourselves to the building industry, "standardization" is in practice largely looked upon as a field of combined regulating activities that not only contains standards in the formal, clinical sense but building codes and systems of quality labeling as well. This field of activities has been schematized below.



As for the concept of "thermal insulation" one should look for the common denominator of the terms of reference of ISO/TC 163 [2], CEN/TC 89 [3] and relevant national standardization commissions

1) Union Européen pour l'Agrement technique dans la construction
2) year of creation: 1975; chairman 1975 - 1985: prof. Lars Erik Nevander, chairman since 1986: prof. Arne Elmroth.
3) year of creation: 1976, reactivated 1988, chairman since 1988 prof. Lars Erik Nevander.

This common denominator can be summarized as: "Climate control and energy consumption of buildings'. Separate fields of activities within the total scope are lined up underneath:



This scheme presents headlines and certainly has no pretension to reflect all individual scopes of the various subcommissions and working groups that are (or have been) of the job.

Distinction should be made between methods to determine elementary parameters as mentioned in the column on the left hand side and main features of indoor climate and energy consumption as lined up on the right hand side. The determination of the thermal transmittance [4] of a system and the determination of the interior surface temperature at a given location on a surface - which together form the essentials of the heading "thermal insulation" - take up an in-between position. These quantities depend, apart from the geometrical characteristics of the system, on elementary parameters as the thermal conductivities of the materials involved and radiative and convective phenomena at surfaces.
In turn, the thermal transmittance of a system and the interior surface temperature at a given location are no more than part of the input data necessary to determine the heating load/energy consumption and the risks of surface condensation respectively.

4) or on an equivalent basis: its reciprocal "the thermal resistance'

It appears that the actual concept of thermal insulation covers only a small part of the general scope of the technical commissions involved. Nevertheless the determination of thermal transmittances and interior surface temperatures by simplistic, approximate calculation has for decades been an integrating part of the activities of building practitioners at all levels. It is therefore worthwhile to spotlight its history and development from an angle of standardization. Leaving experimental methods (hot box measurements, thermography) undiscussed does not mean an underestimation of their importance. Activities in these fields however are the exclusive domain of experts, putting building practitioners in a position of more or less immature by-standers.

Simplistic approximate calculation of the thermal transmittance

Clause 2.12 of ISO standard 7345: "Thermal insulation - Physical quantities and definitions" gives the following definition of thermal transmittance:

> The heat flow rate in steady state conditions divided by the area and by the difference in temperature on both sides of the system:

$$U = \frac{\phi}{(T_1 - T_2)\,A}$$

The standard explicitly remarks that ... "it is assumed that the system, the two reference temperatures T_1, and T_2 and other relevant boundary conditions are defined."

However logical the above assumption may sound, hardly any building practitioner seems to bother about properly defining "the system". Generally a more or less representative part of a building element is traced out and subsequently adopted silently as "the system". The geometrical and thermal boundary conditions along the perimeter of the building element are largely ignored and therefore the results of U-value calculations are bound to be ambiguous.
This way of approach has been promoted by erroneously holding a simplistic, approximate calculation method (i.e. averaging out the different reciprocals of <u>local</u> values of $\{ \Sigma \frac{d}{\lambda} + \Sigma R_s \}$ as a genuine definition of the thermal transmittance. Uncareful phrasing in early-day national standards also helped creating the misunderstanding. The first (provisional) edition of the Dutch standard NEN 1068: "Thermal properties and ventilation of dwellings, issued in 1951, stated that ... "over limited area's (20 %) thermal transmittances are allowed that are 0,3 W/(m$^2 \cdot$ K) higher than the maximum U-values given in the table of requirements".

The successive edition of NEN 1068, that was issued in 1964 among others changed over from thermal transmittances to thermal resistances and it classified building elements on the basis of their R-values as "poor", "sufficient" or "good". The latter category contained all structures with $R < 1{,}3$ (m$^2 \cdot$ K)/W. The standard also contained the requirement that ..." if in a structure the thermal resistance is not the same at all locations, it has to be considered what inconvenience surface condensation at unfavourable locations will bring about and whether or not that is to be tolerated". So here again there was the mix up between the concept of a <u>total</u> and that of a <u>local</u> characteristic. The 1981 edition of NEN 1068 presented a definition of the thermal transmittance along the lines of clause 2.12 of ISO 7345 and defined the thermal resistance as ... "the reciprocal of the thermal transmittance, reduced with a quantity depending on the nature of the system and the direction of the heat flow". So at last clear distinction was made between the definition of the concept and the recipe for the (approximate) calculation of its numerical magnitude.

In 1986 the first international standard was to appear in this field: ISO 6946-1: "Thermal insulation - Calculation methods - Part 1: Steady state thermal properties of building components and building elements".

This standard presents a simplistic, approximate calculation method. The recipe comes down to first dividing the system into sections and layers, subsequently determining the absolute minimum possible value of the thermal transmittance (U') and the absolute maximum possible value (U'') and finally establishing the thermal transmittance as: $U = 0{,}5(U' + U'')$.

The most recent edition of the Dutch standard NEN 1068, issued in August 1991 has basically adopted the same method and so has a working draft for a European standard prepared by CEN/TC 89/WG2. However, before going into more detail with respect to these two documents, attention must be paid to interior surface temperatures.

Interior surface temperatures

In the cold season the temperature at the interior surface of a building envelope will have different values from location to location. From a point of view of estimating condensation risks, those locations where the lowest surface temperatures can be expected are particularly relevant. They are, among other to be found at two- or three-dimensional corners where different building elements meet. In some countries it has become customary lately not to consider the interior surface temperature itself, but a dimensionless parameter called the "interior surface temperature factor" and for which the symbol "f" is adopted. It is defined by the formula:

$$f = \frac{T_{si} - T_e}{T_i - T_e}$$

where:
T_{si} = the interior surface temperature (in K)
T_e = is the exterior environmental temperature (in K)
T_i = is the interior environmental temperature (in K)

Like T_{si}, the quantity f has only local significance.
For surface locations near the central area of large, homogeneous building elements the determination of f is simple enough. This is because at these locations $\frac{T_{si} - T_e}{T_i - T_e}$ approximately equals $\frac{R_{se} + \Sigma \frac{d}{\lambda}}{R_{si} + R_{se} + \Sigma \frac{d}{\lambda}}$, the parameters of the latter form being easy to define numerically.

However, to determine f-values at locations that are critical from a viewpoint of surface condensation (i.e. "thermal bridge location"), the use of numerical calculation models becomes mandatory. International standardization activities in this field have been taken up by CEN/TC 89/WG1: "Thermal bridges and surface condensation".

Towards a European standard on the determination of the thermal transmittance

As was mentioned earlier, CEN/TC 89/WG2 has prepared a working draft for a European standard on the (simplistic, approximate) calculation of the thermal transmittance of building elements. The same subject is covered by part 3 [5)] of the latest issue (August 1991) of the Dutch standard NEN 1068. That part is going to be a *formal* source of reference in the new Dutch national building decree that will replace the old model building code from 1st January 1992 on. The linking up between building decree and standard made that standard (and many others related to the building industry) more or less part of the law. This has lead to specific requirements for the relevant standards with respect to the schematical build-up, the texts being unambiguous more than ever and the omission of all sources of reference other than those standards mentioned in the building decree.

When preparing part 3 of the standard NEN 1068 it proved necessary to devote special attention to:

- the definition of a "separation structure" (being "the system" as meant in ISO 7345 clause 2-12)
- the introduction of the concept of the "projected area" of a structure
- unambiguous recipes for the transformation of a building element in its actual form into the basic scheme underlying the simplistic, approximate calculation method.
- unambiguous statements for the schematization of the perimeter of a building element, including the adiabatic status of the edges.

In the discussions during the last phase of the preparation there regularly appeared a controversy between the wish for simplicity on one hand and the wish to be sufficiently detailed on the other hand. Representatives of the ministry of hosing in the standardization commission were usually successful in pleading for the first.

The European standard that is in preparation by CEN/TC 89/WG2 is expected to come forward with a calculation recipe that, like the one in NEN 1068-part 3, is basicly the same as presented in ISO 6946-1. However it should be regarded of the utmost importance that the items of special attention that have been lined up above are thoroughly discussed at forth coming meetings. Reasonable efforts should be made to prevent that in future European standards end up in a drawer, some of their essentials having been transferred silently to annexes of national building codes.

5) title: "Calculation method for the determination of the thermal resistance of a separation structure"

Gunnar Essunger
Former technical director of Boverket
Sweden

Utilization of building research for building codes and development of the code the last 25 years

The traditional background

1. Originally, public building codes and regulations were drawn up as by-laws within regions of limited extent, normally a municipality. Usually, the regulations consisted of rather general specifications based on local materials, craft skill and empirical knowledge. According to experience the solutions were considered satisfactory.

2. The traditional building materials available were restricted to stone, clay, timber and forge-iron. However, the technical progress, such as the development of new materials, mechanization of the constructive work, increased prefabrication of components and introduction of sanitary installations, gave rise to changes of the regulatory system. It was more and more obvious that the traditional system caused trouble, red-tape and disadvantages.

The pre-code period

3. In the thirties, it was recommended by the parliament that the local by-laws should be uniformed with the aid of a model document. As this step did not led to any material result, a further step was taken in the middle of the forties, when it was prescribed in the building ordinance that certain technical provisions in the by-laws be replaced by directions issued by the central building authority.

4. In the end of the fifties, a new building ordinance was issued. Simultaneously, the parliament decided that sector requirements on buildings, e g on fire protection and on sanitary installations, should gradually be involved in the building directions. Such a kind of harmonization has step by step influenced the building regulations at the same time as sector regulations have been exchanged or abolished. However, this ”domestic” harmonization has not yet been completed, after more than 30 years, e g concerning electric and gas installations and civil defence shelters.

5. When steps were taken in the forties, after the second world war, to establish harmonized provisions, available information and knowledge were gathered, and considered by a comprehensive code committee. The preparation of the provisions was carried out in close contact with the parties concerned, also the technical universities. The experience of the by-law applied by the local building authority in Stockholm was particularly taken into account.

6. Concerning load-bearing structures, the national admistrative boards for construction works of various kinds had issued rather up to date directions, which were incorporated in the public provisions. These directions were based on research results and careful investigations and in that way in harmony with the times. Applied in the public provisions, these advanced rules gave the ordinary ”house building” a qualified technical injection, which some of the parties involved maybe not yet were fitted to assimilate.

The new order

7. Already in the first editions of the provisions in 1946 and 1950, problems related to the building physics were thoroughly elaborated. Particularly, in the revised "pre-code" (BABS 1960) prepared in connection with the new building ordinance rather comprehensive sections on moisture protection, thermal insulation, and protection against noise were given, based on revelant research reports mostly published by the new Building Research Committee (SBN). Concerning thermal and acoustical comfort the rather advanced provisions were expressed, as far as possible, in quantitative functional terms which however, again, caused some complications for the large mass of the code users. Most of these provisions were related to harmonized test and calculation methods prepared in Nordic (NKB) and, concerning acoustics, also international (ISO) cooperation.

8. The efforts in the late fifties to find ways to rationalize the building activity and to put press on the increased building and housing costs resulted in new technical solutions and prefabrication of building components. The technical competence within the ordinary building field increased step by step within all circles. According to a "million-programme" the entire population should be provided with "good and sound dwellings" and this ambitious policy gave rise to new ideas and unconventional building activity. Several investigating committees put forward proposals regarding measures

- to promote industrialization,
- to create a flexible regulatory and control system encouraging a sound building activity, and
- to establish a new central authority for physical planning and building.

9. The new authority, the National Board for Physical Planning and Building (Planverket), started its activity in 1967 on the base of an action programme summarized as follows:

1. Functional requirements in quantitative terms
2. Optional deemed-to-satisfy solutions
3. Provisions on buildings coordinated
4. Provisions concerning installations incorporated in the building code
5. Optional type approval system
6. Official production control at factories
7. Utilization of the experience of the application of the regulatory system

10. The new order resulted in a comprehensive development during the sixties and seventies starting with the first functional-oriented building code (SBN 1967). Though the goal and the main principles seemed to be rather clear, it was obvious at that time, as at every time, that there is a need of better knowledge, more distinct as well as diversified, to express the essential parameters affecting the human being. Neutral and pragmatic ways to lay down amended requirements and to verify the requirements with objective methods were developed and gradually incorporated in the regulatory system. An advicory "Technical Council", representing more than 20 parties concerned, and several working groups of competent experts assisted the Board. Among these groups one was particularly engaged in the chapter on moistre protection.

Research related to regulations

11. When SBN 1967 was prepared available R&D results were thoroughly taken into account. However, the lack of R&D was also noted. Therefore, a study was carried out with the aim to inspire researchers to pay attention to such subjects that are of special importance for improving the building regulations. But it was also considered urgent to study matters concerning ways to meet the public requirements. In consultation with the technical council of Planverket, a preliminary list of R&D subjects was compiled and distributed to the Building Research Council (BFR which in 1960 replaced SBN) and several other parties concerned for comments. The final result of this activity was in 1970 published in a Report no 10, at the same time as a working programme for the future activity concerning the regulatory and control system was presented.

12. Based on the general policy and fundamental principles concerning the future building regulations, more than 200 R&D tasks were systematicly put into order in the Report no 10. The tasks were graduated by urgency. Consideration was taken to the possibility to carry out the work, e g financing and resechers available as well as the need of steering bodies and working groups etc. In the report it was also informed about programme work going on or in preparation, mainly under the responsibility of BFR. Concerning the need of research on general moistre and dampness problems, it was in the report also refered to an investigation by a "moistre research group" at Lund University. It may be added that in a report (no 52) concerning SBN 1980 the need of R&D work was presented in a similar way as in Report no 10. Again, some 200 projects were defind but not the same as ten years earlier. Several of the proposed projects dealt whith the need of R&D for the preparation of approval guidelines for certain groups of products (see a separate report by Tryggve Degerman).

13. The powerful efforts to base the building regulations on reliable R&D results have, no doubt, influenced the regulations and control system in Sweden*). Within some technical fields, it was not so easy to formulate the requirements in a proper quantitative level. Therefore the qualitative requirements must be supplemented by technical solutions and guiding examples and in that way the code and its supplements and comments also became something of a manual "that cuts both ways". For lack of other easy available, up-to-date information the code was widely spread (more than 60 000 copies of SBN 1975).

*) In his thesis in building control about 1980, Bob Greenstreet, UK, wrote: "There are indications of a total reassessment of building control at present that could radically alter the existing situation in this country. If this is the case, international comparison has shown that much can be learned from Sweden, where powers of control are granted by a general enabling law to a central department (Statens Planverk). As the regulations (the Svensk Byggnorm) do not have to be approved by Parliament, they can be written in simple terms, heavily illustrated with diagrams and explanatory data to aid designers in their comprehension. Furtermore, the regulations are sufficiently flexible to allow simpler requirements for smaller dwellings and minor building works, and are backed up by a sophisticated method of testing and approving standards of materials and methods of construction."

Nordic and international development

14. In the sixties and particularly in the seventies, a comprehensive Nordic and international cooperation started within the building field concerning R&D and also in order to harmonize building regulations and control systems. Unfortunately, it was not possible to reach to a treaty between the Nordic states to introduce jointly the guidelines agreed upon by the Nordic Committee on Building Regulations (NKB) in their national regulations. Therefore, as I, once upon a time a bit disapointed noticed: "Only the Swedish regulations became harmonized." This is a pitty. A little more courage of the goverments in the end of the seventies would have given us all a better position in relation to the comprehencive harmonization activity now going on within the European Economic Community (EEC).

15. Nevertheless, Swedish and Nordic ideas were presented in Europe. In 1973, the first seminar (the London seminar) on removal of technical barriers to trade was organized by the Committee on Housing, Building and Planning within the Economic Commission for Europe (ECE). In an introductory report*), I discussed the possibilities and ways to harmonize building regulations. Several proposals were presented in order to organize the international intergovermental cooperation. Research work required for the preparation of building regulations was considered in the report and some proposals were presented, inter alia against the background of the Swedish study on R&D needs for building regulations. In the report it is mentioned: "It is desirable that international organizations cooperate in carrying out the R&D tasks which are of common interest to authorities responsible for building regulations. It is primarily CIB and RILEM which should participate in this work, but other international organizations which are engaged on scientific matters relating to the building sector, such as technology, medicine, sociology and economy, should also be interested in taking part. International cooperation may be organized regarding the physiological and psychological reaction of the human organism to the physical and social environment. Serious efforts have to be made with a view to feasible application of functional (or performance) requirements in building regulations. It is also urgent that the influence of data processing on the building industry and building regulations be studied."

16. During the last seventies and early eighties, several proposals and recommendations have been prepared by the Working Party on Building, based on a programme which was elaborated on the findings of the London seminar (e g ECE/HBP/52, 55, 62 and 67). The most remarkable result of the ECE activity is the redrafted and consolidated version of the Model Provisions for Building Regulations – the first international publication of this kind (ECE/HBP/81). Several of these recommendations have been influenced by research results presented by working groups in CIB, RILEM, CEB, JCSS and others. The Nordic countries have supported the work in various ways, also using R&D results related to the cooperation in NKB and Nordtest, e g on structural reliability, indoor climate, thermal insulation and fire protection.

*) The report was based on an enquiry to several European countries, information from NKB and a document on building control in some western European countries, compiled by the Building Research Establishment (UK).

Ways and means for expressing requirements

17. The scientific research and the technological development have also influenced principles for building regulations and other general problems. An industrialized production as well as a wider building market requires a new approach concerning the ways to shape a flexible regulatory system. Requirements can be expressed in accordance with the following rough order:

a) Descriptive requirements setting out the technical specifications of the solution.
b) Functional requirements setting out the required function in qualitative terms.
c) Performance requirements setting out the required performance (derived from the functional requirements) in quantitative terms.

18. The descriptive requirements can obstruct technical development as well as international trade. Qualitative requirements are somewhat indistinct as it is not so easy to objectively and unambigously verify that the requirements are met. Therefore, nowadays the intention is, as far as possible, to give the requirements according to the *performance approach in quantitative terms*. This way to proceed has been developed in cooperation with researchers about 15 years ago.

19. Within some regulatory fields the performance approach is well in use. Such a field concerns structural performance requirements due to the fact that international scientific cooperation started several years ago. Requirements on protection against noise are also rather well in line with the performance approach. The same may be said concerning thermal comfort and energy conservation.

20. When considering means of expressing performance requirements within certain fields, many difficulties can become apparent. It is necessary to be somewhat pragmatic in order to define realistic parameters which are not too sophisticated for the users of the code. The true doctrine of the performance concept is probably not always possible to follow. Therefore, it may be stressed that there is a need of more research within this special, but very significant sector. So it is an important task for researchers to study this subject in cooperation with the code writers.

Current principles

21. The improvement of the public regulatory system is doubtless of common interest for all parties within the building field. Summarizing the current tendencies the following principles should be underlined:

a) Public building regulations should concentrate on requirements relating to essential functions of importance to the users.
b) As far as possible, the parameters applied in defining quality requirements should not be tied to any specific materials, structures or production methods.
c) As far as practicable, the requirements should be expressed in quantitative terms so that the required performance levels can be verified by means of objective methods.

According to these principles it should be left to the parties involved in the building operation to develop and introduce the technical solutions that meet the public requirements. Such solutions can be presented in type approvals or standards according to agreed principles.

22. For the time being, the interest and main activity concerning the regulatory and control system in the building field is concentrated on the work going on within the European Economic Community (EEC). The goal of the Construction Products Directive (CPD) is a free internal market for products which are fit for their intended use. That means that the products shall have such properties that the buildings, "properly designed and built", in which the products are incorporated fulfil the essential requirements given in the directive. This twofold aim has given rise to an important regulatory activity which may be of interest for researchers and code writers. The relation between the essential requirements on the buildings and the key properties of the products will call for research and investigations on suitable parameters and levels of performance characterizing the products (see a separate report prepared by Tryggve Degerman).

A further step for the future

23. Dealing with the improvement of building regulations, it may be paid attention to the fact that the quality of buildings are laid down not only by society (i e parliament, government and proper authorities) but also, in accordance with contracts and other agreements, by the clients (including their designers and investors, insurers and users). Therefore, R&D work and new ideas must be undertaken within this "unregulated" field. In Sweden, Planverket took some steps in this direction in the end of the seventies. Thus, the preparation of manuals and other valuable information was promoted. Some such manuals were published about ten years ago. One of the most important may be mentioned at this occasion, Fukthandboken, prepared under the leadership of Lars Erik Nevander who also acted as main author. Thanks to this valuable manual, the corresponding part of the code could be reduced and related guidance rules abolished.

24. Unfortunately, this positive and farseeing measure was not carried on, probably due to the lengthy and confused discussions and deliberations concerning the new building legislation and obviously also other problems. However, when the final solution concerning the new building code became clear, an initiative was taken by the Swedish Building Centre, in cooperation with Planverket/ Boverket and other parties concerned, to compile and improve available knowledge related to the code and its application. As a result, a series of guidance documents are in course of publication, named Byggvägledning, containing useful examples of solutions and methods as well as comments encouraging progressive evolution and good practice. In my opinion, such publications can play an important role for the bulding industry as a refreshing source of knowledge related to public regulations and inter alia also workmanship specifications. R&D centres might be responsible for supplying the publications with fresh knowledge at appropriate occasions, so the parties within the building operation can have the use of up-to-date means for a creative activity. This idea may be considered by interested parties in order to agree on convenient ways to act. I would like to add that an idea similar to what I have outlined several years ago was put forward in a paper by Lars Erik Nevander.

Tryggve Degerman
Type Approval Office of Boverket
Sweden

Type approval and production control of building products in Sweden

Since the middle of the fifties, an optional system for type approval and production control of prefabricated building products has been in operation in Sweden. The activity has gradually been developed. In 1967 the basic rules for the activity were incorporated as an official part of the national regulatory and control system. According to the building legislation in force, the National Board of Housing, Building and Planning (Boverket) is authorized to approve products in relation to the requirements in the legislation and the supplementary regulations issued by the Board.

The aim of the approval and control system is to support the development and use of new products and to promote prefabrication and industrial production. The system will facilitate and simplify the quality assurance by the producer as well as the supervision by the client and the local building authority. The production control is of particular significance in the case of products which cannot be easily and reliably checked on a building site without undue interference with the product.

The comprehensive development within the building field and the ongoing industrialization have increased the interest for and also the possibility of producing products carefully designed and manufactured at factories applying quality assurance programmes. According to the experience in Sweden, the approval and production control system has facilitated the possibility to reduce the amount of building regulations and to replace some of them with guidelines for groups of products. The technical specifications has been left to the parties involved in the building operation to develop. In that way technical barriers to trade can be removed and a free trade in project-anonymous products may be promoted.

During the last years about 700 new and revised type approvals have been issued annually. More than 2 000 approvals are for the time being in force. Most of them are related to the structural framework, secondary elements and finishes. A fourth part deals with installations for water supply, waste water, heating and ventilation. Information about approval and controlled products is published twice a year by the Swedish Building Centre.

Approval procedures

An application for type approval of a group of products shall be accompanied by drawings and related calculations and test reports according to the guiding rules issued by the Board. If the properties of the products are deemed to be fit for the intended use of the product, an approval certificate is issued. In this certificate and the attached documents the way to perform the production control is laid down as well as the conditions under which the product shall be incorporated in the building. The certificate is normally valid for a period of five years.

The applicant has to pay a fee for the certificate in accordance with a time tariff. On the other hand, the fee to the local building committee for receiving a building permit is reduced, when approved and controlled products are used.

In connection with type approval of products, deviations from the requirements in the building regulations may be allowed, provided that the products is nevertheless considered to be satisfactory for its purpose. For approved and controlled products, more favourable design values may under special circumstances be permitted than for products which are not subject to such control. A basic condition for these special prospects of using the system is that the products are carefully calculated, designed and produced and the approval application thoroughly scrutinized.

Production control

The production control is supervised by bodies designated by Boverket according to the legislation, in first hand the National Testing Institute and agencies jointly organized by the industry and the authorities.

The agencies are working in accordance with rules adopted by Boverket. Representatives of Boverket and some other authorities are members of the boards of the agencies and have jointly the carting-vote in principle matters. According to the rules in force the control is normally arranged as follows:

a) Before the manufacturer is accepted, the control agency inspects the factory and makes sure that everything is in order so that the intended quality of the products may be expected.

b) The internal production control shall be carried out under direction of a person responsible for the quality and according to a quality programme accepted by the control agency.

c) The factory shall be inspected by the control agency, usually at least two times a year, in order to supervise that the internal control takes place in accordance with the programme.

d) In connection with the inspections, specimens for testing by the National Testing Institute shall be selected for comparison with requirements according to stated documents and testing carried out by the manufacturer.

The Swedish approval and control system has step by step been developed and has had a considerable influence on the building industry and on assessment procedures. According to relevant guidelines, it is possible to take into account the statistical documentation of the continous tests and checking. Based on these results and other conditions, e.g. the manufacturing method and the factory production control, the producer has to lay down the procedures in a quality programme, accepted by the control agency. This approval and control system has gradually increased the interest of the building product industry for well-arranged design and production procedures.

Guidelines

In order to facilitate for the building industry to prepare applications for approval of products and related production control, special guiding rules have since several years been issued by the central approval authority. All these guidelines are now being revised. In first hand the general rules for approval and production control will be redrafted.

When preparing revised and new guidelines, Boverket has the intention to take into account as far as possible requirements and recommendations in the CPD. Of great interest are also the advisory notes and procedural rules prepared by the SCC and EOTA. As the rules within this field, applied since about 30 years in Sweden, are very much in line with the principles in the CPD, this coordination would probably not cause any particular problems.

Nordic and European cooperation

Since several years, a comprehensive Nordic cooperation is going on within the building sector on research, regulations, type approvals, standards, test methods and production control. Based on recommendations adopted by the Nordic Council of Ministers, Nordic guidelines for approval of groups of products have been prepared by the Nordic Committee on Building Regulations (NKB). Products approved in accordance with these guidelines in one of the Nordic countries are accepted in the other Nordic countries according to a simplified procedure.

Naturally, this cooperation has been influenced by the European activity regarding technical approval. In June 1990, after that Finland, Norway and Sweden had received full membership of UEAtc and in March 1991, joint seminars have been arranged in Stockholm and Oslo in order to inform the industry about UEAtc guidelines and confirmation procedures as well as about the creation of EOTA and its activity. An informal working group, "ETA-Nordic", has been established in order to promote the European cooperation.

Margareta Andersson
Building Standards Institution (BST)
Sweden

Is modern building physics research implemented in national and international standards?

Dear Lars Erik,
Ladies and Gentlemen

There are very strong links between research and standardization. In the field of building physics the input from research into standardization has been good and I would like it to continue that way. But research and standardization are two different processes that must be kept apart. Why, well I would like to elaborate a bit on that.

First, what is a standard? In my own words I would say that a standard is a recommendation to do something in a certain way. It could be used as a means of communication between the parties concerned and should open up for fair competition. The idea is to simplify the transfer of information, especially when the same information would otherwise have to be repeted. A standard is drawn up by manufacturers, users, authorities and other interested parties. The standard is a volontary document and will not be used unless the users of the standard find that it provides a practical and economical solution. However, today there is also a trend to refer to standards from building regulations which means that a standard might become obligatory.

If we look at standards in the field of building, they will serve as tools in the building process. The contents of these standards thus influences the cost and quality of our buildings and also the living conditions. The standard should therefore be regarded as an important document in the building process. Standards in the field of building physics are no exception. On the contrary they are very important tools in designing and improving of our houses and other buildings. However, in order to draft the best up–to–date standards we need research and research results.

The changes in building technology have been great over the last years. There are many reasons for this. The first oil crises led to more energy efficient buildings. But this has to be combined with healthy buildings and environmental aspects. These considerations have encouraged the use of new constructions and new materials or old materials used in a new way. Our traditional knowledge is not always sufficient to judge how a structure or building will function. We have to take into consideration the effects created by new materials and the new way of building. I am not saying that we should not be innovative but we need tools to predict the effects.

You find faults and damages also in high quality buildings. One of the reasons is that we do not have sufficient knowledge to solve the new problems. We need more and new knowledge in the fields of building technology and building physics. More knowledge about materials and constructions and how they will react in practice. This leads to a need for methods to test, evaluate, predict and assess both the materials and products as well as the complete building or structure.

It is, however, important that we in addition to collecting more knowledge and experience also develop tools that can be used by a large group of people involved in the building process. These tools could and should and will in many cases be standards. This shows that there is a great need for cooperation between standardization and research. Not only in the field of building physics, but that definitely is one of the important sectors.

If we look back at the standards that have been produced by ISO, the International Organization for Standardization, in the field of thermal insulation, we find that the majority are terminology standards, test methods and calculation methods.

To have an agreed terminology is the best way of avoiding unneccessary discussions and misunderstandings. It is, of cource, used in the other standards produced in that field but what about research documentation? Would it not be much easier to read a report of a collegue if she or he used the same symbols and terminology as yourself? Well, even for a terminology standard it is essential that it is up–to–date. It has to be drafted by persons with a very sound knowledge of the field and it must not conserve old fashioned expressions, quantities or ways of thinking?

Two principal test methods were published as late as last month. It is the heat flow meter method and the guarded hot plate method. Neither contains any detailed requirements regarding the design or size of the apparatus. The designer of an apparatus is given large freedom with regard to the temperature range and the geometry of the apparatus. Instead, the accuracy of the test result is specified as limiting values for the apparatus performance and the testing conditions. This unfortunately leads to fairly long and complex standards. To give a detailed design of one apparatus would be easier but by giving performance requirements it is possible to improve the apparatus and measurement techniques within the present standard.

The calculation methods are to be seen as design tools and reference to such calculation methods will in many cases be made from building regulations. Sometimes they have to be supplemented with input data specific to a certain country or climatic region but the general philosophy could be the same worldwide and the results thus, hopefully, comparable.

When it comes to product specifications, only one ISO Standard dealing with mineral wool pipe sections has been published. There are some in the pipeline but the large quantity of product standards is to be expected from the European Committee for Standardization, CEN. Even if CEN is preparing one specification per material, e g building insulation from mineral wool, building insulation from extruded polystyrene foam etc, the intention is to use the same test methods for the different materials. The task then is to find a method that with a reasonable accuracy gives fair and comparable results.

For certain parameters we even try to find methods that are common for all building materials, e g in the field of moisture. In doing that we encounter a lot of problems where a thorough knowledge about how the materials react under certain conditions is essential.

What we need nationally as well as internationally is standards that are up–to–date. Nobody wants a standard based on yesterdays knowledge. However, if you want to base your standard on the knowledge of tomorrow this could mean that you would have to wait for the reseach to be carried out before completing the standard. In that way the standard will perhaps never be finnished. What remains as a basis for standardization is the most advanced knowledge of today. By doing that we can and should implement research results in our standards. But at the same time we must keep standardization and research apart. Standardization must not become research but should make use of research. Standardization is a process of finding support for an idea, a process of collecting and incorporating the veiws of the different parties involved. A standard should give a solution that is acceptable to as many as possible.

Not all research is suitable for or aiming at finding solutions to common problems. But in case of projects where the results could be implemented in one way or the other in the building process it would be of great value if the project was reported in a way that would simplify the implementation. This would involve an extra effort of the researcher but it definitely would encourage the use of the findings in the standards work. This effort would probably not seem to big if, at the same time, the researcher could look at standardization as a means of promoting research results. By incorporation in a standard your collected knowledge could be spread to a larger group. Perhaps in a simplified form, but valuable results could come into practical use without unnecessary delay instead of being hidden in a research report which is read by a limited number of specialists.

By presenting the research result in a way that would simplify its introduction in the standards process a lot of time and misunderstandings would be avoided. A continued contact with the research person would also be of value in the standards process. Here, the researcher must be open to the needs and wishes of other parties with a different background and representing different interests in the building process. Even if the standard is based on research it must obtain broad support. This becomes even more obvious in international standardization where different cultural, climatic and technological factors influences the comments and votes on a standard. Sometimes a country expresses a negative opinion just because it lacks experience in that specific field. Again my wish is that standardization could be seen as a tool to spread information not only within a country but also between countries.

There is another role for the researchers from universities and other institutes in the standardization process. As I said, the role of standardization is to collect the veiws of all parties concerned. It may be contractors, producers of building materials, testing institutes and authorities. Even if the latter in many cases has the task to guard the consumers, the researchers could play an important role here. To find a true consumers' representative is very difficult and even if you could it would in many projects be difficult for that person to participate in the sometimes complicated discussions between technicians. A research person from an institute or a university could in many cases be a good representative for the users or consumers.

I am convinced that the need for research results and cooperation with researchers will be even more obvious in future standardization. When drafting standards research results must be used. It is important that the standards are up–to–date.

Gösta Dahl
Siporex, Euroc
Sweden

Aerated concrete - A building material for the future?

(A new start for aerated concrete?)

If you are asked to say something about the future it can be of interest to look backwards as a start. In the beginning of the thirties nearly all dwelling-houses and industrial buildings in Sweden were built in brick or wood or in some cases in a combination of these materials. The brick buildings were either made with bricks in the facade or rendered. The wooden houses were made of solid plank or battens and often rendered on the outside.

This was the situation when the aerated concrete was introduced on the market. In the beginning the material was only produced in the form of unreinforced blocs for walls.

Compared with the traditional materials the aerated concrete had some advantages. It was cheaper by volume. The work on the building site was cheaper. It was a good bearer of rendering and it had better thermal resistance.

In the thirties there were three Swedish companies. Ytong, Durox and Siporex. New factories were built all over the country and the technic was also exported to other countries.

The reinforced slabs for floors, walls and roofs were developed. A majority of all industrial buildings in Sweden in the fourties, fifties and sixties were built with aerated concrete slabs in walls and roofs.

There were no really good competitors until the middle of the sixties. Then the gypsum board took the market for partition walls. The technic with stick and wad, this is what we a little disrespectful call the construction of crossbars and mineralwool, a cladding of bricks on the outside and gypsum board on the inside took most of the market for outer walls on dwelling-houses. The corrugated steel plate constructions took a big part of the market for walls and roofs on industrial buildings.

The market for aerated concrete contracted; and today the Durox Company does not exist any more in Sweden, the Ytong Company has one factory left and so has also the Siporex Company. This is the situation in Sweden today.

But what about the future?

Of course I will speak about that too, but first I want to give you some informations about the qualities of aerated concrete.

1. The rawmaterials for producing aerated concrete are common in most countries. They are limestone, sand, cement and water and all of them are available in big quantities and will last for a long time.

2. The process for producing the material requires small quantites of energy. The sand is milled and mixed with the lime, cement and water. To this slurry aluminium powder is added just before pouring the slurry into big moulds. The reaction between lime and aluminium produces hydrogen gas which is foaming the slurry up and makes the cells in the material.

   After some hours of hardening the material is cut to blocs or slabs with thin steel wires and put into autoclaves. The autoclaves are heated with watersteam to about 180 ° C and a pressure of about 12 bars. The autoclaves are well heat insulated and the temperature is kept up by the chemical processes going on. At the same time the hydrogen gas in the cells is changed to watersteam. After 10 to 12 hours the material is ready.

3. The manufacturing of blocs is always readymade before the autoclaving and most of the slabs are also made in the soft mass. This has the advantage that the material which is cut away can go back into the slurry and only blocs and slabs with big damages are wasted. The waste material is used to restore the nature where sand or rock has been taken away.

4. Most blocworks of aerated concrete are today made with thin-joint (2 mm) mortar with minor influence on the U-value than the former used joints of about 10 mm.

   The slabs for floors, walls and roofs are today to almost 100 % mounted with a crane. The further development of the tools for this is going on and this is very important for the economy of the whole concept.

5. <u>The function in the building</u>

   5.1 If we start with the drawbacks. The material is sensitive for freesing and thawing if it is saturated with water. Such high concentrations of water are very exceptional but it can occur on top of horisontal surfaces whithout any protection. The freesing and thawing must also be repeated for several years before you get any damages.

5.2 The material has after the autoclaving a certain amount of moisture in it. The moisture above 25-30 % by weight is totally transported by capillary suction within the material and this transportation goes very fast. Below this limit the transportation is totally diffusive and goes very slow.

The consequence of this is that in two or three weeks you can dry the outer 25 to 30 mm of walls and roofs in a new building. Then the rest of the moisture inside the construction diffuses so slow through the already dry part that it can evaporate from the surface without problems for the costumers.

5.3 The material is friendly to the environment. It is a stone-material which does not smell or give away any gases and does not irritate the skin or give you allergic problems. It does not give you silicosis when you grind it or work with it in other ways.

5.4 It cannot rot or be the basis for mould. If there is something wrong with the ventilation system or if there are other exceptional circumstances it can happen that there will be mould on the surface of the aerated concrete. This can occur behind bookshelfs, mirrors, paintings behind glass, or other places where the air is not moving. If this happens it only happens in the first summer when the relative humidity indoors is high. The mould cannot find nuitrition in the material itself but in organic materials such as paint, wallpaperglue etc.

The point is that this occur within three months after the people have moved in and not after two or three years and not in the interior of the constructions where it cannot be seen.

If the indoor climate is normalized the mould is not growing any more and in easy cases it can only be brushed away. In more severe cases the wallpapers or the painting has to be renewed. A very important point is that the house will not be a sick house. In the last 10 years we have had only two cases of mould growth and in both cases there were problems with the ventilation system, FTX, which has steered air (From and To together with a heat-exchanger). Part of the explanation of the good result is good information made by our salesmen. They inform the customers about the importance of not placing bookshelfs, mirrors, paintings and so on close to the walls in the first three months after moving in into a new house. They also inform the people on the building site about the importance of drying out the building before painting etc.

Do not speak with us about sick houses. Speak with us about healthy houses.

5.5 The hygroscopic movements are very small. The thermal movements are somewhat smaller than for steel. This gives pretension in the steelbars in slabs when they cool down after the autoclaving.

5.6 The material itself is airtight and gives with the technic used today buildings with a good airtightness which is energysaving.

5.7 The material has a fairly good compressive and shear strength. It is strong enough for making loadbearing slabs for floors, walls and roofs.

5.8 It has fairly good thermal resistance. It gives low U-values with moderate thicknesses of the constructions. By varying the recipe and the foaming it is relatively easy to adapt the λ-value and strength for different purposes.

5.9 It is a good basis for different kinds of rendering, both organic and of lime-cement type.

5.10 The material and its qualities makes it possible to construct a wall with <u>one</u> material in <u>one</u> homogeneous layer. This makes it difficult to scamp and easy to check. It is a safe construction.

The labour cost on the building site is fairly low and this is one of the main points which gives a positive view of the future for the material.

6. The ageing properties are very good. We have many buildings from the thirties which are as good as new ones. Of course you must do the maintenance work as for all other buildings.

Compared with a wooden facade on private villas, which must be painted at intervals of about five years, our glassfibre-fabric reinforced organic rendering requires repainting at intervals of 25 to 30 years. A thick lime-cement rendering of good quality, reinforced with a welded and corrosionprotected steelnet, may stand for a hundred years.

7. The main basis for our optimism about the future for our material is the new Swedish Building Code. It does not concentrate only on the U-value as the old one did. It takes into consideration all factors influencing on the energy consumption for a building such as

The thermal resistance of the total envolope of the building.

The airtightness of the whole building.

The heat-capacity of the building.

The orientation of the windows.

The capacity of eventual heatpumps or recuperators.

By taking advantage of the airtightness of our constructions, the heat-capacity of our material, and by using good windows we can compensate for a moderate U-value. For dwelling-houses we must also compensate by a well insulated roof (mostly made with mineralwool).

To this we can also add what I have said before that so far we have not yet known of any "sick" houses built in aerated concrete. If there is anybody who knows about a sick house made in aerated concrete I am very interested in informations about it.

It is a hard job and cost a lot of money to inform all potential customers about these new possibilities for our material but I think we can manage it.

8. The deciding factor for the future of the material is of course the total costs for the complete constructions, compared with the quality.

As a conclusion of this it is up to our company to keep pace with the competitors in rationalizing the production, to invest in research and development to improve the material, the handling equipment, the different surface treatments and all other side-activities that influence on the total costs for the customer.

Sune Nilsson
Sune Nilsson Ingenjörsbyrå, Malmö
Sweden

WILL THE (FLAT) ROOF REMAIN WATER-PROOF?

The question head-lining my lecture "Will the roof remain water-proof?" could, I think, have been given a more objective answer by Lars-Eric Nevander himself rather than by someone who has dedicated his entire professional life to roofs. An interesting job might give you an emotional attachment.

Now, however, the question was put to me and then it should probably concern "my" flat roofs. With the nearly 60-year-old history of flat roofs as a back-ground, I will try to give my opinion on the present situation as well as on future possibilities.

When the functional architecture first came to Sweden in the early thirties, it was the first time that we heard of "flat roofs". In the beginning the slope was seldom less than 10 degrees. The construction was a ventilated wooden roof, covered with bitumen felt (*Picture 1).*

In the late forties, the market for flat roofs increased strikingly due to the fact that industrial halls were constructed with roofs of slabs of cellular concrete *(Picture 2)*. The rapid development - more than four million square-meters of roof per year - caused problems. Damages and leakages caused people to question the flat roofs' "to be or not to be". *(Picture 3).* The genuine work done by the Council for Building Research in cooperation with the manufacturers of building material and contractors resulted in instructions that more or less solved the problems.

In the early sixties, the market for flat roofs increased even more - in 1965 more than 10 million square-meters were produced. At the same time new construction methods were introduced, for instance the insulated steel deck *(Picture 4)* as well as new insulation materials, for instance slabs of polystyren or mineral fibre *(Picture 5)* and new roofing materials, such as felt of glass fibre, plastic or rubber. Roofs without slopes *(Picture 6)* were constructed as well - quite unsuspectingly - and in practice this resulted in water remaining on the roof as well as ice-covering. Everything happened so quickly that there was not time for evaluation of experiences.

In the mid-sixties Lars-Eric Nevander introduced his "Division of Building Technology". He himself and collaborators and his students focused on several of the difficult roof-problems that otherwise could have had severe and expensive consequences.
The head-line clippings from research- and investigation-projects that I have brought with me are only a few examples on the activities in Lund during this period *(Pictures 7 and 8)*.

The fact that standards were low on roofs built in the sixties and seventies was confirmed to us by an investigation made on behalf of the Council for Building Research and the Development Fund of the Swedish Construction Industry in 1987 *(Picture 9)*. The report on the standard of the roofs was based on a grading of approximately 2 000 objects constructed 1950-1980 and made by the real estate owners and -keepers. The 4-graded scale should be interpreted as follows:

1: a failed roof
2: a roof with problems
3: an acceptable roof
4: a good roof.

About 25 per cent of all roofs were rated as failures or problem-roofs, that is grade 1 or 2. Within the group "horizontal roofs" more than 50 per cent were rated as not satisfactory.

Due to reluctance within the building industry it was not until the end of the 70:ies that the experiences and research-reports led to changed techniques and higher demands for materials and construction methods.

It started 1978 with "Advisory Notes and Recommendations to Workmanship Specifications for Building" (HusAMA) *(Picture 10)*. This was the first time that the "Performance Criterias" were applied - that is demands based on presumed influences - though they had already been advocated for by Lars-Erik Nevander since more than ten years *(Picture 11)*.

Since the beginning of the 1980:ies there has fortunately been a distinct improvement in the standards of new-produced roofs as well as of renovated ones. An inventory of 500 renovated roofs, conducted 1989-90, shows an average grade of 3.5 according to the grading method described earlier. It should be observed, however, that those objects were only 3-12 years old *(Picture 12)*.

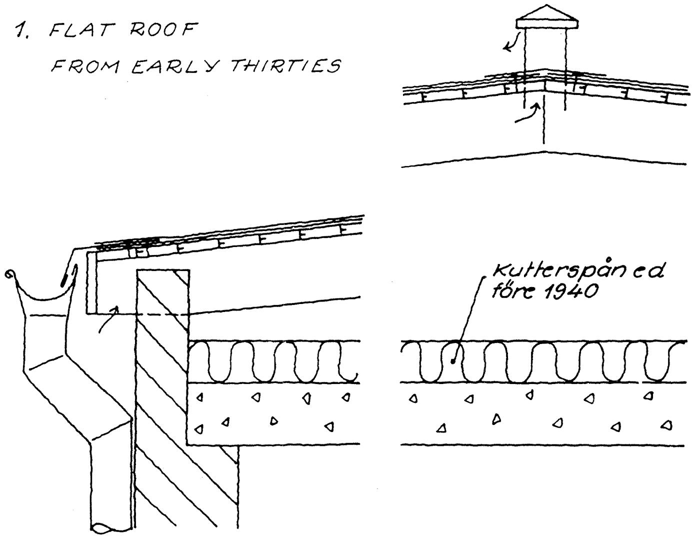
A more recent research document from 1990 -"Weather-proofing membranes on roofs" - is completely based on "Performance Criterias" *(Picture 13)*. This report can therefore form the basis for, for instance "Type Approval in Connection with the Swedish Building Code". The same report also presents internationally accepted testing methods for membranes on roofs. This should guarantee that the approved materials presently in use are adjusted to the influences.

Even though the total number of damages has diminished radically, there is still room for more improvements. At my damage-inventories I have noticed that as far as the causes of damages are concerned there has been a marked shifting towards lack or fault in workmanship . Approximately 70 per cent of the leakages on flat roofs can be related to workmanship and mainly to work on details. My observations correspond well with those made by a Dutch colleague, N A Hendriks *(Picture 14)*.

My answer to the opening question will therefore be concluded as follows:

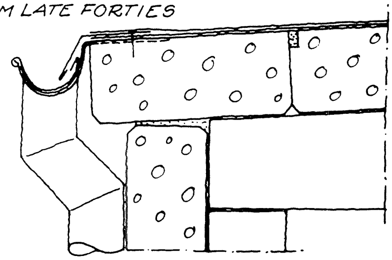
When even more improvements in the workmanship have been made, including control and inspection of the work, even the flat roof will remain water-proof.

1. FLAT ROOF
FROM EARLY THIRTIES



Låglutande sadeltak ("plant" tak) på bostadshus
Från början av 1930-talet.

2, FLAT ROOF ON INDUSTRIAL HALLS
FROM LATE FORTIES



"Plant" industritak från 1940-50-talet:
Prefab betongstomme, takelement
av gasbetong och klistrad 2-lags-
täckning med takpapp.

3. ROOF SEMINAR 1950

Hur skall man utforma ett "plant" tak?

Ordförande: Lektor Gustav Winberg

Inledare: Civilingenjör Rune Hanson

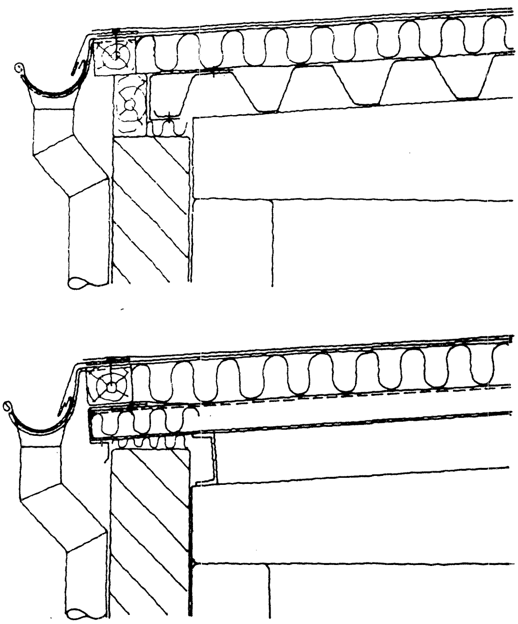
THE FLAT ROOF, TO BE - OR NOT TO BE

Det plana takets vara —
eller icke vara

Civilingenjör Åke Hallgren, Sverige

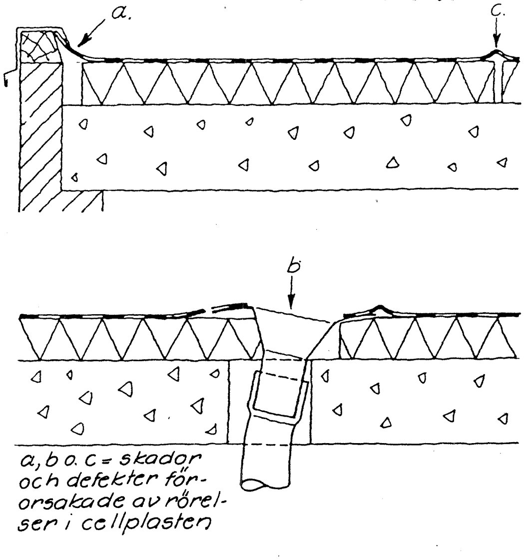
Rubriker från nordiskt takseminarium 1950

4. INSULATED STEEL DECK FROM EARLY SIXTIES



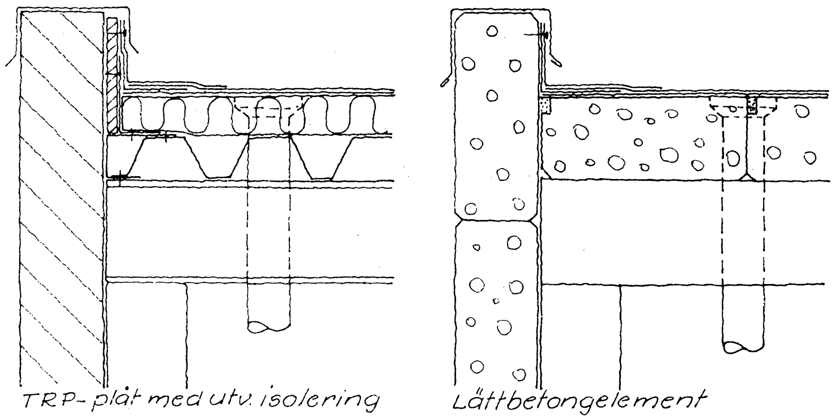
Tak av TRP-plåt ("lätta" tak), med utv. värmeisolering och papptäckning. Början av 1960-talet

5. HORIZONTAL ROOF INSULATED WITH POLYSTYREN



Horisontellt tak: Betongbjälklag med utv. isolering av styrencellplast och asfaltklistrad papptäckning. Från början av 1970-talet

6. HORIZONTAL ROOFS ON INDUSTRIAL HALLS. FROM LATE SIXTIES



TRP-plåt med utv. isolering

Lättbetongelement

Horisontella tak på hallbyggnader Från slutet av 1960-talet

8.

INSTITUTIONEN FÖR BYGGNADSTEKNIK
TEKNISKA HÖGSKOLAN I LUND
DIVISION OF BUILDING TECHNOLOGY
LUND INSTITUTE OF TECHNOLOGY

FUKT I UTVÄNDIGT ISOLERADE PLÅTTAK

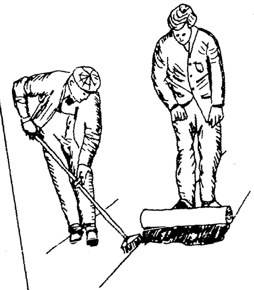
MOISTURE TRANSFER IN STEEL DECK

INGEMAR SAMUELSON

LUND 1976

WATERPROOFING MEMBRANES ON ROOF

INSTITUTIONEN FÖR BYGGNADSTEKNIK
TEKNISKA HÖGSKOLAN I LUND
LUND 1974



TÄTSKIKT

P. I. SANDBERG

7.

FLAT ROOFS - MOISTURE PROBLEMS?

FUKTGRUPPEN VID LTH
LUNDS TEKNISKA HÖGSKOLA

FLACKA TAK - FUKTPROBLEM?

SEMINARIUM 1982-09-08

ROOFING MATERIALS

Yttertaktäckningsmaterial

Sven Strandberg 1981

ROOF

INSTITUTIONEN FÖR BYGGNADSTEKNIK LTH

LUND 1973

TAK

I SAMUELSON

MAINTAINANCE - CAN WE TRUST OF ROOF MASTICS

professor Lars Erik Nevander
civilingenjör Behzad Golrang

1986

Kan man lita på TAKMASSAN?

INSULATED FLAT ROOFS - VAPOR BARRIER OR NOT?

INSTITUTIONEN FÖR BYGGNADSTEKNIK
TEKNISKA HÖGSKOLAN I LUND maj 1975

DIVISION OF BUILDING TECHNOLOGY
LUND INSTITUTE OF TECHNOLOGY

Ångspärr eller ej?
Beräkning av fukttillstånd i utvändigt isolerade tak

Per Ingvar Sandberg

9.

R100:1987

REJECTED AND GOOD ROOFS

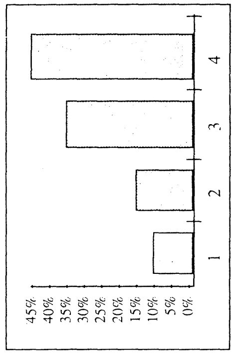
Rune Hanson
Sune Nilsson

The houseowners' marks of the roofs

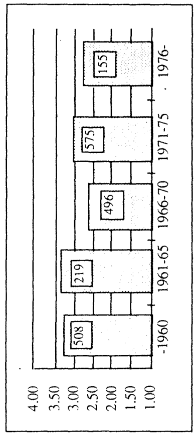
Criterion for marks

- Rejected roof = 1
- Roof with problem = 2
- Acceptable roof = 3
- Good roof = 4

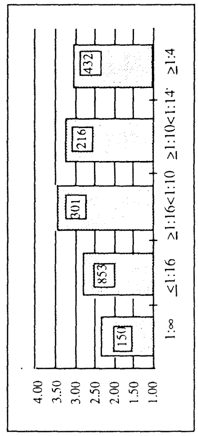
1. Marks all roofs (~2000)



2. Marks with regard to date for building

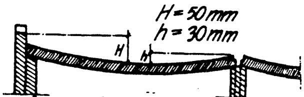


3. Marks with regard to slope

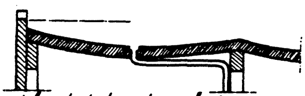


10. WORKMANSHIP SPECIFICATIONS FOR BUILDING

RA78 HUS



Långdsektion, alt. 1 Fel!
wrong!



Långdsektion, alt. 2 Rätt!
right!

Nya Råd och anvisningar till Hus AMA 72

WATERPROOFING MEMBRANES

Performance requirements

Krav på tätskikt av papp på yttertak

Tillåtna toleranser för "horisontella" tak enligt Hus AMA 72 (överst) och rekommenderad placering av takbrunn enligt reviderade råd och anvisningar RA 78 (nederst)

Ytskikt	Skyddsbelagd papp		Singel
Taklutning	≥ 1:100 (0,6°)	≥ 1:16 (4°)	≥ 1:100-≤ 1:16
Krav: Brotthållfasthet vid dragning kN/m	25	15	20
Brottöjning %	10	2	10
Töjning med bibehållen täthet %	5	1	5
Stansmotstånd mejsel, N	200	150	200
Stansmotstånd cylinder, N	900	500	900

12.

R 86 : 1990

FLAT ROOFS

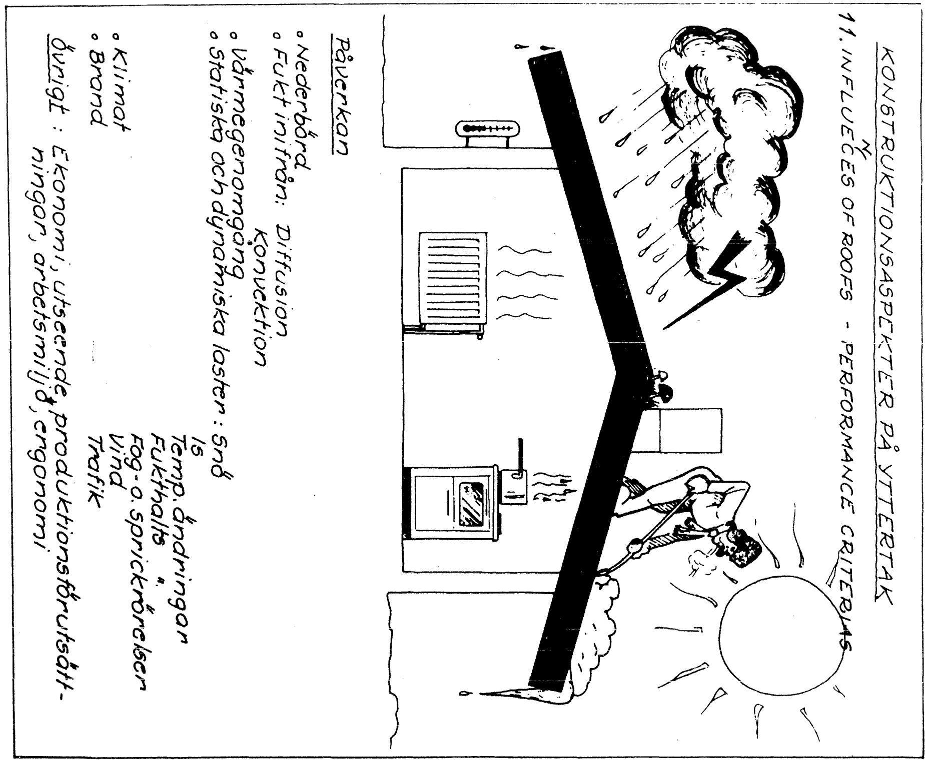
500 Renovated objects

Rune Hansson
Bertil G Johnson
Sune Nilsson

Age: 3 - 12 years

The house-owners' marks of the roof with regard to the new waterproofing membrane

Membrane		Share %	Marks
Rag felt		8	3,35
Polyester felt	ox.b.	31	3,71
"	SBS	5	3,73
"	APP	24	3,70
"	Element	8	3,58
PVC		9	3,68
ECB		11	3,15
Other		4	3,80
			$\bar{X}$= 3,61



14.

WATERPROFFING MEMBRANES ON FLAT ROOFS

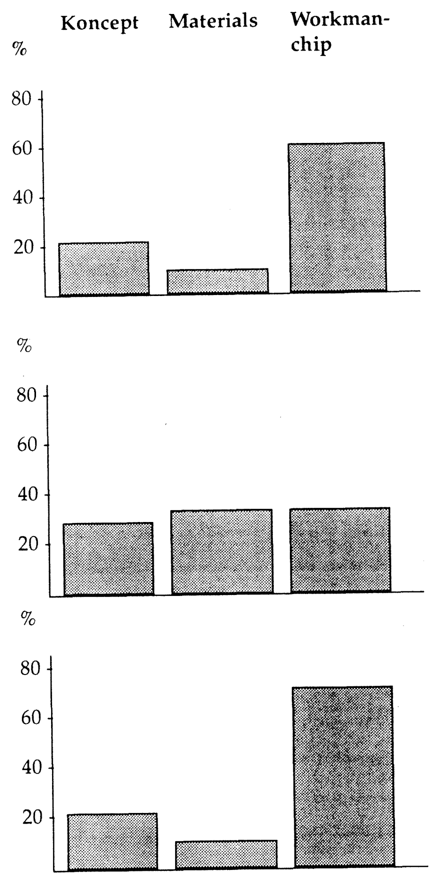
Judged reason to damage (leakage)

Defectives or fault in

According to NA Hendriks, Holland

According to Sune Nilsson Date for building - 1979

1980 -



13.

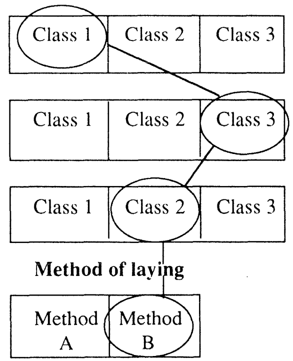
WATERPROOFING MEMBRANES ON ROOFS

Performance requirements- fundamental requirements

Fundamental requirements

- Watertightness
- Resistance to ageing
- Sliding at high temperature
- Dimensional stability
- Resistance to ignition by flying brands
- Protection against slipping
- Adhesion of protective covering

Performance requirements - related to stresses in the individual building



Ability to accommodate movement

Resistance to mechanical action

Resistance to fatique

System safety

The above example shows membrane type 132 B.

In order that a weatherproofing membrane shall comply with the requirements for membrane type 132 B, the appropriate fundamental requirements and the requirements represented by each number and letter shall be complied with.

Sune Carlsson
The Swedish Brick and Tile Manufacturers Association
Sweden

THE CLAY BRICK - AN IMPORTANT PART OF BUILDING PHYSICS

Bricks is the common name of units for masonry made of different materials - clay, cement etc. Clay bricks are units made of fired clay. The Swedish name is 'tegel', which is said to come from latin 'tegere', i.e. cover.

Fired bricks were originally used as an outer layer protecting a brickwork built of unfired bricks. Brickwork has still often the same function, i.e. to form a climatic barrier for less weather-resistant components in the wall.

Brickwork of clay bricks is also used for many other purposes in the building construction:
- loadbearing
- sound insulation
- sound absorption
- thermal insulation
- thermal storage
- fire division

Some of these functions are utilized in outer walls, others in partition walls. That implies that the brickwork is utilized optimally if both the loadbearing structure and the outer walls are masonry.

In addition we have the aesthetical aspect - a very important quality which, however, can't be measured in definable values. An interesting fact is that a beautiful exterior is less liabel to vandalism than a dreary one. We also use to say that a clay brick facade gets a patina while other walls are grewing dirty.

The performance of brick-work in fire division constructions and in sound insulation walls are well known. The use of perforated bricks as sound absorbents is also well established. In connection with these functions the advantage of the exterior values and the durable surface of the brickwork should be and is often taken into consideration.

But the brickwork doesn't always satisfactory fulfil all desired or required functions. To achive for instance thermal insulation to actual Swedish standard with only brickwork of ordinary Swedish bricks would demand a wall thickness of more than 1 meter.

In other European countries - Austria, Switzerland, Germany - clay block walls are used without addition of high-grade insulating materials with great success. The wall thickness is 0.4-0.5 meter with a lambda-value of 0.2-0.4. This is a result of energetic research, cooperation between brickmakers and good marketing activities. They try hard to improve the lambda-value by developing products with high porosity and labyrinth formed perforation patterns.

Since the end of the 50-ies brickwork is in Sweden mostly used as a single leaf outside a concrete frame structure with high-grade insulation material in the outer walls. In this respect we differ from design traditions i most European countries where load-bearing brickwork is an essential part of building constructions.

Even our Scandinavian neighbours use load-bearing brickwork. A few years ago in Trondheim in Norway an 8 storey high office building was designed with horisontal and vertical reinforcement. The bearing clay brick walls are only 135 mm thick and are carrying floor structures with a span of 16 m in both directions.

The outer walls are insulated with mineral wool and cladded with a clay brick leaf. The building cost was 30 alternatives. The design was made in cooperation with the Norwegian brick-work organization Mursentret.

This Norwegian design is partly similar to our double cavity wall with insulation of mineral wool. This wall has proved to be very reliable in areas with driving rain since there are no components made of organic materials and the construction is therefor practically moisture resistant.

The Brick Panel-wall or cladding, which in Sweden usually is 90 or 120 mm thick, is an important part of the buildings climatic barrier. It shall protect less wheater-resistent components behind the masonry-wooden framework, insulation etc - against the affect from rain, wind and sun. Simultanously the brick-work shall perform as an attractive facade.

Moisture problems in buildings are not new phenomenons but in modern buildings the moisture problems seem to be more embarrasing. In brick panel constructions the moisture usually derives from driving rain and, sometimes but not so often, from condensation. The action of the brick panel is designed to absorb the rain-water. When the rain has ceased the water in bricks and mortar will be drawn to the surface and evaporate. This normally works very well. But when it doesn't work you will be disappointed. The quality of the components - bricks and mortar - will be suspected. The brick-work as a reliable structure will be questioned.

We must recognize that masonry walls can leak through the joints. Penetration of rain-water has two main causes - bad workmanship and/or lacking interplay between bricks and mortar. The construction must therefore be able to drain out the moisture before it can do any harm. This concerns both flowing water and vapour. We know quite well how to drain out flowing water but we know much less about how vapour behave behind a brick panel.

I will mention a special case to illustrate this. We have a problem called 'summer condensation', i.e. moisture diffusing from the warm and wet masonry into the construction behind and condensing on the vapour barrier. Then moisture damage can occur for instance on wood studs close to the barrier. We know that this 'summer condensation' occurs now and then but we don't know how often and how much.

Since a couple of years a research program is going on here at LTH in order to find out how air and moisture behave inside the construction and in the space next to the masonry. We want to know if there is any essential ventilation through the air space, how important the width of the space is, how in- and outtake of air should be designed etc.

The wheather conditions - temperature, wind, sun - have proved to have great influence on the air-flow behind the brickwork. The problem is that these conditions change frequently. It would be much easier if the wheather would be steady but as we know it isn't so.

In addition to moisture problems, damage on the brick-work itself may occur. The facade sometimes becomes discoloured or bricks and mortar get split by frost. Frost damages occurs in the brick-work in connection with driving rain and frost.

During the 60-ies and 70-ies the brickmakers processing technique improved considerably and notifications of damages decreased at the same rate and the problem with frost was considered as a minor matter. After the winter 1980 all these conceptions were turned around. A big number of frost damages were reported and many of them with a different pattern than they used to be.

It was soon established that the wheather conditions during this winter had been extrem and was not comparable to any year during this century. The damages also disclosed some remaining errors by brick production. After 1980 frost damages are again very few and have usually reference to grave errors in material production or building design or workmanship.

However, some feeling of uncertainty remains and the demand for an efficient freezing test is topical. The method we use now is not useless but there are defects. The test results are uncertain in relation to natural stress in the brick-work. There is also a subject of discussion if you should test the components or the brick-work. At Murforum at LTH a method is developed for testing brick-work during various conditions. This method seems to be useful for research purposes but not for quality assurance systems.

In connection with the standardization work in progress for EC by CEN the problem about a common freezing-test method is a topic of interest. Proposed standards for units and mortar etc as well as for testing methods except freezing are made. A big project is now started in order to select from a number of national methods one method which can be accepted of all countries as EN standard.

My intention with this paper is to point out that even such an old design as clay brick masonry, whose characteristics in most cases are well investigated and well known, still can be improved by research, cooperation between producers and users, product development, method development and good marketing activity.

LUND UNIVERSITY
Division of Building Physics

Symposium to celebrate professor Lars Erik Nevander's 70 years birthday

Research and Development in Building Physics during the last 25 years

13/9-1991 IDEON β2, Lund

List of participants

L. Alenrot	Pilkington	Sweden
G. Anderlind	Gullfiber AB	Sweden
M. Andersson	BST	Sweden
J. Arfvidsson	Lund University	Sweden
G. Billgren	Byggnadsstyrelsen	Sweden
T. Blomberg	Lund University	Sweden
S. Blomqvist	HSB Riksförbund	Sweden
M. Bomberg	N R Council	Canada
M. Borgström	Chalmers	Sweden
G. Dahl	Siporex	Sweden
T. Degerman	BoVerket	Sweden
F. Descamps	K U Leuven	Belgium
H. Eide	Byggstandard.	Norway
A. Elmroth	Lund University	Sweden
C.-E. Eriksson	Fuktkonsultgruppen	Sweden
G. Essunger	Stockholm	Sweden
B. Fredlund	Lund University	Sweden
D. Gaffner	Lund University	Sweden
Z. Gereben	EMI	Hungary
B. Grandinson	SBUF	Sweden
B. Grauers	Malmö	Sweden
S. Gustafsson	Chalmers	Sweden
C.-E. Hagentoft	Lund University	Sweden
E. Hansen	DTI	Denmark
L.-E. Harderup	Lund University	Sweden
Claerence Hector	Malmö	Sweden
Göran Hedenblad	Lund University	Sweden
H. Hens	K U Leuven	Belgium
B. Hermansson	AB Svenska LECA	Sweden
A. Homb	NBI, Trondheim	Norway
H. Høyer	Rockwool	Denmark
Jan Isberg	Chalmers	Sweden
Bo Jedler	SPF	Sweden
G. Johannesson	KTH	Sweden
Christer Johansson	S P	Sweden
B. Jonsson	S P	Sweden
P. Kalliomäki	Miljöministeriet	Finland
S. Karlsson	Malmö	Sweden

S. Karlsson	Skanska Teknik AB	Sweden
F.J. Kasper	G+H AG	Deutschland
E. Kjellsson	Lund University	Sweden
F. Klavestad	Dow Norge A/S	Norway
S. Klarsfeld	Saint-Gobain	France
P. Knös	Dow Sverige	Sweden
V. Korsgaard	DTH	Denmark
J. Kronvall	Lund University	Sweden
M. K. Kumaran	N R C	Canada
G. Kårfalk	Byggnadsfysik AB	Sweden
L.-E. Larsson	Chalmers	Sweden
Sven Lindblad	Teknisk akustik	Sweden
P. Lindroth	BoVerket	Sweden
L. Lindskog	Skanska Teknik AB	Sweden
Alec Loudon	Edinburgh	United Kingdom
M. Matsumoto	Kobe University	Japan
P.-O. Mattsson	Gyproc AB	Sweden
L. E. Nevander	Lund University	Sweden
A. Nicolajsen	SBI	Denmark
A. Nielsen	Narvik	Norway
C.-E. Nilsson	MITU	Sweden
L.-O. Nilsson	Chalmers	Sweden
S. Nilsson	Malmö	Sweden
K. Norling	Chalmers	Sweden
L. Olsen	DTI	Denmark
T. D. Pettersen	Narvik	Norway
B. Petterson	Byggforskningsrådet	Sweden
C. Rode-Pedersen	DTH	Denmark
P. Roots	Lund University	Sweden
I. Samuelsson	S P	Sweden
P. I. Sandberg	S P	Sweden
A. Sandström	AB Svenska LECA	Sweden
H. Sasaki	Hokkaigakuen	Japan
M. Serkitjis	Chalmers	Sweden
Cao Shenghan	Henan Province	China
C.J. Shirtliffe	N R C	Canada
O. Smith-Hansen	Rockwool	Denmark
C.-G. Stadler	Rockwool AB	Sweden
I. Ström	Malmö	Sweden
B. Suleiman	Chalmers	Sweden
B. Svennerstedt	LBT	Sweden
K.-E. Synnemar	Byggförlaget	Sweden
R. Taesler	SMHI	Sweden
E. Tammes	Ijssel	The Netherlands
R.P. Tye	Massachusetts	USA
P. Wallenten	Lund University	Sweden
L. Warringer	Skanska Teknik AB	Sweden
B. A. Zarrabi	Chalmers	Sweden
O. Åberg	Lund University	Sweden

An international symposium on Building Physics was held in Lund, Sweden, in September 1991 to which participants were specially invited who had worked with Lars Erik Nevander during the time of his professorship at Lund University.

The book is dedicated to professor Lars Erik Nevander who turned 70 in the autumn of 1991.

The papers provide an interesting overview of advances in Building Physics during the last 25 years both in Sweden and internationally. They deal with such differing topics as heat insulation, moisture transport, measuring and sampling techniques, wall construction, roofing, and both national and international building standards.

Art.No:6822015

D15:1992
ISBN 91-540-5497-4
Swedish Council for Building Research
Stockholm, Sweden

Distribution:
AB Svensk Byggtjänst
S-171 88 Solna

Approx-price: SEK 130