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Building Physics and Design

Physique des constructions et projet

Bauphysik und Entwurf

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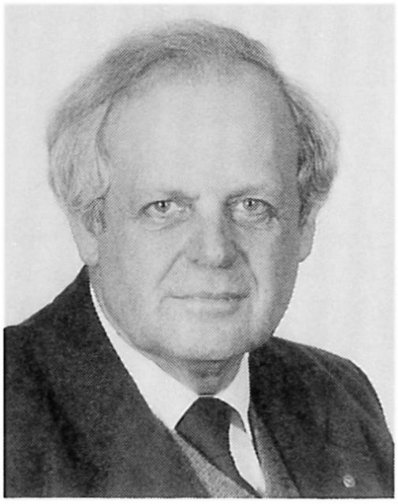

Bo Adamson, born in 1925, received his doctor's degree at the Royal Institute of Technology, Stockholm, Sweden 1955. He is professor in Building Science since 1964 at Lund University, Sweden. He is involved in research concerning energy conservation of new and existing buildings, heat and mass transfer in building materials and components as well as heat and mass balance in buildings.

SUMMARY
Building physics is involved in all stages of building design and concerns mostly heat and mass transfer in materials and components as well as radiation. The paper discusses problems as heat flow in ground, temperatures in non-transparent building components, energy transfer through windows, moisture migration and storage in materials and structures, fire exposed structures and air movement in rooms and spaces. The paper shows that simulation of the physical processes is the basic for an increased knowledge but it is often stated that the agreement between simulations and measurements in occupied buildings could be better. This is discussed in a section "Theory and practice" in the end of the paper.

RÉSUMÉ
On retrouve la physique des construction à tous les stades des projets de construction, ceci concerne surtout le transfert calorifique et de masse dans les matériaux et les composants, ainsi que la radiation. L'article traite de problèmes tels que la circulation de chaleur au niveau du sol, les températures dans les composants non-transparents des constructions, le transfert d'énergie à travers les fenêtres, la migration et le dépôt d'humidité dans les matériaux et les structures, l'exposition au feu des structures et le mouvement de l'air dans les chambres et les espaces. Ce travail montre que la simulation des processus physiques est une bonne base pour une meilleure connaissance mais on constate souvent que la corrélation avec les mesures effectuées dans des constructions habitées pourraient être meilleures. Ceci est discuté dans le chapître "Theory and practice" en fin d'article.

ZUSAMMENFASSUNG
Die Bauphysik spielt in allen Stadien des Gebäudeentwurfs eine wichtige Rolle, vor allem was den Wärme- und Feuchtetransport in Materialen und Bauteilen betrifft. Dieser Beitrag behandelt den Wärmefluss in den Untergrund, Temperaturen in nicht-transparenten Bauteilen, Energie-übertragung durch Fenster, Feuchtetransport und -aufnahme in Baumaterialen, feuerexponierte Bauten und die Luftbewegung in Räumen und Zwischenräumen. Es wird gezeigt, dass die Simulation der physikalischen Vorgänge das Verständnis verbessert. Im Abschnitt "Theorie und Praxis" wird die Tatsache diskutiert, dass die Uebereinstimmung zwischen Simulation und Messungen am Gebäude oft besser sein könnte.

1 INTRODUCTION

Natural science is the basis of building design. Other necessary desciplines are aesthetics, function, psychology and physiology. Within natural science mechanics, physics and chemistry are used, and we have subjects such as:

- building statics
- building dynamics } structural mechanics
- building physics
- building chemistry
- building biology

The most interesting topics in building design are those in which more than one subject is involved, as for example structural mechanics and building physics. Other interesting topics of current interest are rot, mould and smell in buildings, in which structural mechanics, physics, chemistry and biology are involved.

Building physics covers subjects such as:

1) heat transfer by conduction, convection and radiation as well as heat storage by sensible and latent heat
2) mass transfer and storage (moisture, air and gases)
3) heat and mass balances in rooms and buildings
4) fire and fire resistance
5) lighting
6) acoustics

All these subjects, except item 5, are more or less related to structural mechanics. Subjects such as energy conservation and air pollution are not specifically mentioned despite the fact that they are very important. They need different areas of physics for their solution.

The aim of this paper is to give an introduction to some problems chosen from research fields of which the author has some knowledge.

2 HEAT FLOW IN THE GROUND

Heat flow in the ground influences the foundation structure in two ways. Firstly, if the ground consists of frost heaving soil the foundation can be affected by frost heaving forces. Secondly, the heat flow determines floor temperatures and heat consumption. Since the end of the 1960s computer simulations have made possible the solution of two- and three-dimensional transient heat transfer problems which also consider latent heat and temperature-dependent thermal conductivity and heat capacity. Figure 1 shows isotherms in a ξ-z section (a vertical section through the diagonal of a 10x10 m building in north Sweden), Adamson, et al 1972.

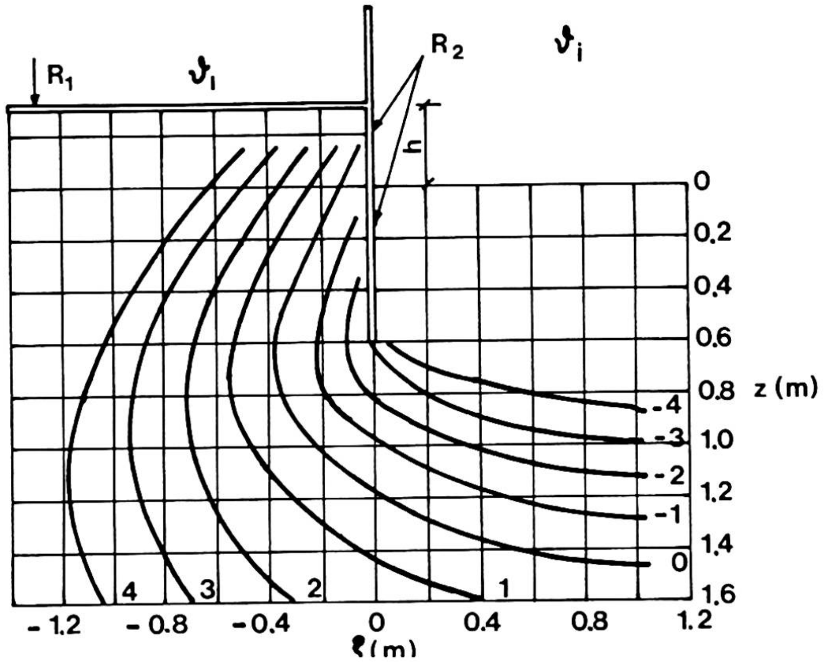

Fig.1 Isotherms, 4 weeks after the lowest outdoor temperature, in a vertical ξ-z section of a house of 10x10 m foundation area. Indoor temperature = +20 ^{o}C and outdoor air temperature = $+4.4+17.4 \cos\omega t$. Snow-free ground. h=0.3. Floor insulation R_1=1.08 m^2K/W and foundation wall insulation R_2=1.08 m^2K/W for $-0.3 \leq z \leq 0.6$ m.

3 TEMPERATURES IN NON-TRANSPARENT BUILDING COMPONENTS

Building components such as walls and roofs are influenced by air temperatures and radiation as well as evaporation and condensation of moisture. Very often surface temperatures are calculated with standardized surface heat transfer coefficients. Air movement, shortwave (solar) and longwave radiation must be taken into account if a reasonably accurate temperature is to be calculated. A number of computer programs which can calculate surface temperatures and temperatures within the component by considering convection, radiation and conduction, are available. Normally such programs do not take evaporation and condensation into account. Unfortunately, outdoor climatic conditions such as solar and longwave radiation to the sky are not well known. Moreover, future shading by other buildings and vegetation is not known at the design state.

It has been shown that the colour of the outer surfaces of a building is of critical significance for both surface temperatures and the heat flow through the component. Adamson, 1987 shows that the heat flow through walls and roof can be increased by 5-15% in Chinese climate by changing the colour from dark to white.

If the temperature stresses or deformations are to be calculated it is necessary to carry out an accurate calculation in which all the above parameters are taken into consideration. We need better simulation methods and experimental validation of the programs. Otherwise a calculation will be merely a conjuring trick which deludes both the performer and the audience.

4 ENERGY TRANSFER THROUGH WINDOWS

The glazed part of a window has earlier been treated in a very simple way. The U-value has normally been calculated without considering daylight radiation and windows have been regarded as very heat consuming building components.

Attention is now given to the transmission of solar energy into rooms and it is part of the heat supply to heated buildings. In climates with high temperatures solar radiation will increase the cooling load. An accurate simulation of the energy transfer through the glazed part of a window is necessary.

Selective coatings and gases other than air between panes have given better insulation properties to sealed glass units but have also changed the temperatures of the sealed unit. Besides the heat balance, calculation of temperatures in the glass material and in the seal must take the energy absorption and energy transfer into consideration in an accurate way. The JULOTTA program, Källblad 1987 gives an example of such an accurate method. Table 1 sets out heat requirements and maximum room air and glass temperatures of glazed parts with various properties. The glass temperature can rise from 36 to 56 ^{o}C if a specific selective coating and argon are applied to a double glazed sealed unit. The annual heat requirement will for this specific building decrease by 15%.

Glass unit	Selective coating 1) Transm	Absorp	Emiss	Annual heat requirement kWh/yr	Annual max temp Room air ^{o}C	Inner glass surface ^{o}C
Double glazed 2)				11629	32.8	35.9
Triple glazed 2)				10533	32.7	40.6
Quadruple glazed 2)				10072	32.7	43.9
Double glazed with selective coating and argon:						
Old type: (gold)	0.58	0.15	0.09	10127	32.7	43.8
Sb-doped SnO_2	0.55	0.30	0.13	9984	34.0	56.2
New type (silver)	0.64	0.15	0.12	10079	33.3	44.0

1) on normal 4 mm glass
2) normal 4 mm glass

Table 1 Annual heat requirement and maximum room air and glass temperatures for an apartment in Swedish climate. South facing glass area =7% and north facing glass area =3% of the floor area.

5 MOISTURE MIGRATION AND MOISTURE STORAGE IN MATERIALS AND STRUCTURES

Moisture conditions in materials and structures are of great concern in new buildings. Rot, mould and smell are problems in all types of climates. In cold climates energy conservation and extreme insulation have been blamed for this, but the reason is of course that architects and engineers have not designed and/or constructed the building in a proper way. Knowledge of migration, condensation and storage of moisture is limited and, moreover, that knowledge is poorly disseminated among architects and engineers.

For very well defined boundary conditions and for materials which are very well known from the point of view of moisture, such as well defined concrete, moisture migration can be calculated also for a transient flow. For most materials such as brick, aerated concrete and wood, future moisture conditions cannot at present be predicted very accurately. The materials are not homogeneous and they vary from one consignment to another. Moreover, the moisture conditions are dependent on the moisture history of the material, and that history can cover many months. Knowledge of the behaviour of components and structures must be based on a qualitative knowledge of migration, condensation (evaporation) and storage of moisture combined with analysis of the behaviour of components and structures in practice. Calculations must take into consideration the variation of boundary conditions and moisture properties.

Research concerning moisture migration etc has to be divided into two groups:

- basic research (increased knowledge) of migration, condensation (evaporation) and storage of moisture

- analysis of components and structures in laboratories and in situ from a heat and moisture point of view

The "Moisture Research Group" (Fuktgruppen) at the Lund Institute of Technology covers both aspects. Among topics the following can be mentioned:

- study of moisture migration in porous materials by the "Moment"-method
- moisture diffusion of concrete, cement plaster and water-cement paste of high moisture content
- moisture migration in wood of high moisture content
- heat and moisture conditions in ventilated crawl spaces
- moisture conditions in walls of aerated concrete

Preliminary results are published in annual reports.

6 FIRE EXPOSED STRUCTURES

In the last few decades, great advances have been made in the mathematical modelling of compartment fire and the design of fire-exposed loadbearing structures. The fully developed or postflashover compartment fire is most widely studied. During the past 20 years a number of simulation models have been developed. Hamerthy and Mehaffey, 1983 have classified 14 mathematical models of compartment fire.

The fundamental characteristics for a full description of the postflashover fire are the variation in time of the following factors (Pettersson, 1983):

1) rate of heat release
2) gas temperature
3) geometrical and thermal data for external flames
4) smoke and its optical properties
5) composition of the combustion products, particularly toxic and corrosive gases

Factors 1-3 concern structural safety.

The models available are applicable to compartments of room size such as dwellings, ordinary offices, schools, hotels etc. For compartments of very large volume such as industrial buildings and sports halls a postflashover model gives an unsatisfactory description of the worst thermal condition of the structure. In such cases a preflashover model of the conditions near the structural members will give a better prediction of the worst case.

For timber structures exposed to fire, an analytical model for calculation of the rate of charring and moisture conditions in uncharred portions is necessary. Fredlund, 1988 has studied this problem. Heat transfer in the material is assumed to take place as conduction and convection when the volatile pyrolyses products and the vapour move in the pore system of the wood. The original moist wood material is assumed to have four phases: active wood which on pyrolyses produces gases, charcoal which oxidises at the material surface, moisture in the liquid phase, and vapour.

The theoretical analysis of the pyrolysis of moist wood involves nonlinear heat and mass balance equations which are solved numerically.

Figure 2 shows an experiment where a piece of pine is exposed to an energy source, Fredlund, 1988.

FIG. 2a FIG. 2b

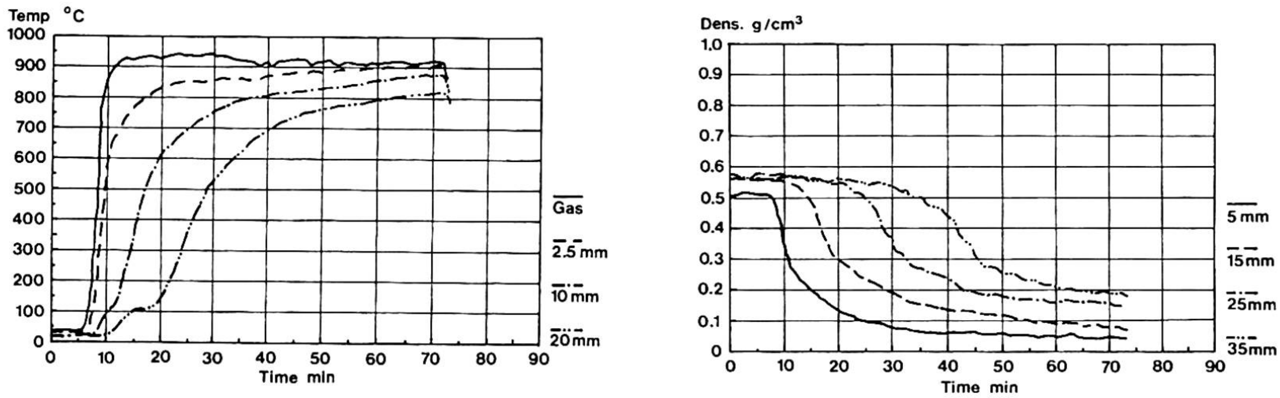

Fig.2 Temperature (a) and density of material (b) in a test where Pine (moisture content =13.5%) is exposed to 95 kW. (Fredlund, 1988).

7 AIR MOVEMENT IN ROOMS AND SPACES

Air movement in rooms and spaces is of interest for many reasons such as

- convective heat transfer in closed spaces
- temperature distribution in large rooms
- smoke distribution from a fire
- ventilation efficiency in ventilated rooms

Air movement in closed spaces has been simulated by a number of mostly two-dimensional mathematical models. Figure 3 shows calculations made by de Vahl Davis and Mallinson, 1975 for a space containing oil and Figure 4 shows the horizontal temperature distribution in the middle of a sealed glass unit with different Rayleigh numbers, Jonsson, 1985. It is shown that the air stands still if Ra=8000.

Air movement in very large rooms is of interest from many points of view. It influences:

- heat consumption
- ventilation efficiency in occupied zones
- temperature distribution in the room
- smoke distribution in the event of fire

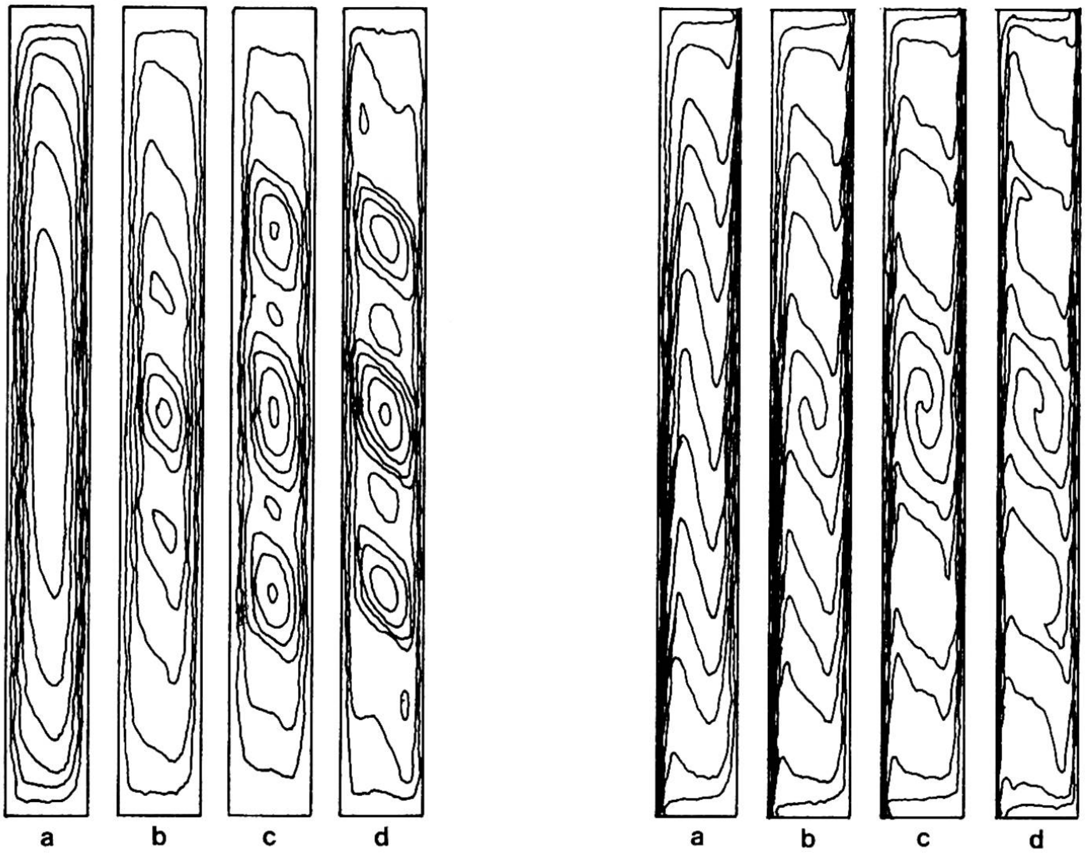

Fig.3 The stream function and isotherms in a space (height L and width d) for L/d = 10 and Pr = 1000 (oil) and Ra = a) $2.4*10^5$, b) $5.0*10^5$, c) $9.4*10^5$ and d) $33*10^5$ (de Vahl Davis and Mallinson, 1975).

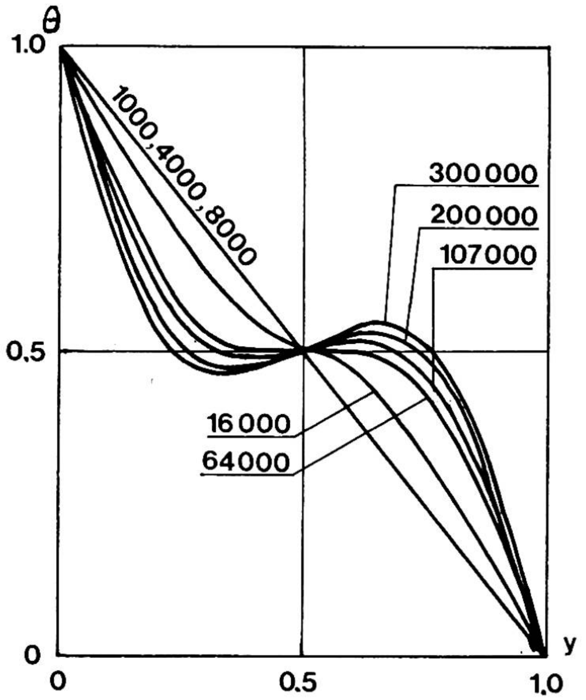

Fig.4 Horizontal temperature distribution in an air-filled vertical space at x/L=0.5 (middle). L/d=20, Ra=1000, 4000, 8000, 64000, 107000, 200000 and 300000. (Jonsson, 1985).

Air movement and the temperature distribution in glazed spaces between buildings or attached to buildings are of interest nowadays. Insolation will increase the temperature of floor and walls, and will give rise to air movements and temperature gradients in the space.

A number of simulation programs have been developed and used for the above mentioned problems, as for example PHOENICS, TEACH and FLUENT, see Whittle, 1986.

Computer programs can of course also be used for prediction of air movements in normal rooms. However full scale tests are normally used. They can also give results for occupied rooms under non-isothermal conditions.

8 HEAT BALANCE IN ROOMS AND BUILDINGS

Design of heating and cooling equipments and determination of energy requirements for heating and cooling necessitate accurate calculation of the heat balances of the spaces in a building. Calculation of indoor conditions in uncooled buildings during the hot season also needs accurate prediction of room temperatures and moisture conditions.

A number of programs have been developed and used for prediction of loads, energy requirements and temperatures. The programs have been compared by calculating the same case. Such comparisons have been carried out within the IEA, 1981 (International Energy Agency), Energy Conservation in Buildings and Community Systems Programme. The result is that large differences occur in the calculation of heating and cooling loads and energy requirements. This is due to:

- differences in interpretation of drawings and specifications
- differences in the algorithms used
- differences in the numerical treatment

Comparisons between simulations and measurements are rare, especially for occupied buildings.

A conclusion is that simulations have difficulty in accurately predicting the thermal performance of a building. If the weakness of a program is known the programs can be successfully used for parametric studies, i.e. study of the influence of the variation of a parameter (insulation of walls, number of panes in windows, orientation of windows etc) on temperatures, loads and energies. Such parametric studies have been carried out in our department. They concern different types of climate, Swedish, European, Chinese and Algerian climates. Table 2 shows how improved insulation and reduced ventilation can give an unheated multistorey residential building in the Beijing climate reasonable indoor temperatures also during the coldest days of the year when the outdoor temperature is below -10 ^{o}C.

Case					Room air temperature (^oC)					
Apart-ment	Ven-tila-tion ach/h	Panes	U (W/m^2K) Outer walls	Roof	Middle storey T_{min}	T_{-100}	T_{-500}	Upper storey T_{min}	T_{-100}	T_{-500}
Middle	1.1	2	0.87	0.31	3.0	5.3	7.4	2.5	4.7	7.0
"	0.5	"	"	"	6.5	9.5	11.8	5.9	9.0	11.2
"	"	3	"	"	7.8	10.6	12.9	7.1	10.0	12.4
"	"	"	0.56	"	8.7	11.5	14.0	8.0	11.0	13.5
"	"	"	0.33	0.17	10.0	13.0	15.7	9.6	12.9	15.4
"	"	4	"	"	10.9	13.7	16.2	10.5	13.5	16.1
End	"	"	"	"	9.3	12.1	14.4	8.9	11.9	14.2

Table 2 Annual minimum temperature T_{min} and temperatures T_{-100} and T_{-500} fallen short of 100 and 500 hours per annum, respectively in an unheated building with different ventilation rates, numbers of panes and U-values of outer walls and roof. Glass area facing south is 14% of the apartment floor area. BEIJING 1984. (Adamson, unpublished).

9 COMBINED HEAT AND MOISTURE BALANCE

In a Nordic climate, indoor moisture conditions are not critical for human comfort. In a warm and humid climate, however, indoor moisture conditions play an important part for comfort. During certain periods of the year, moisture conditions may become very uncomfortable if the apartments are not suitably planned and designed.

Calculation of the combined heat and moisture balance is of great interest, and studies have started. This is a field of future research.

10 THEORY AND PRACTICE

This paper has dealt with simulation of physical processes in buildings. It is often stated that the agreement between simulations and measurements could be better, especially for occupied buildings. This has caused more "practical" people to ask: Why use an immense program to calculate the heat requirement of an occupied building when the difference between calculated and measured consumption can be more than 10%? This is a very good question and shows the weakness of simulations. The result of a simulation can only be as good as the input data. If the input data are not accurately known, which they normally aren't in occupied or used buildings, the agreement between theory and practice will not be very convincing.

However, simulations and parametric studies are very good tools to increase our knowledge. Simulation of frost penetration near a foundation was used to shape building regulations. It was possible to study how variations in soil properties, snow cover, insulation etc influenced frost penetration. Simulations of the development of fire and smoke movement also result in regulations and recommendations. Parametric studies concerning indoor temperatures, heating and cooling requirements have resulted in regulations and handbooks.

Conditions in occupied buildings for which a number of parameters are unknown or badly known can probably be predicted by using simplified models in which uncertain parameters are given as an average value and a variation.

Theory is a simulation of nature. At best it simulates nature in a very good way. Practice is nature and therefore a very good theory and practice will coincide. A "practical man" has, at best, extensive experience of real cases (design, construction or operation of a building). But he cannot use his knowledge unless the situation from which the experience originates is repeated. Some circumstances are probably changed, but for the "practical man" it seems that the case is the same. Without a theoretical background it is hardly possible to use experience. A theory gives an understanding of the physical behaviour and gives a framework which helps to organize various experiences.

Building codes and recommendations are simplified. It is most essential that they are physically correct. They should also reflect the theoretical background and serve as an educational instrument. They do not always fulfil that requirement.

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