International Energy Agency

Heat, Air and Moisture Transfer in Insulated Envelope Parts

Final Report

Volume 3

Task 3 : Material Properties

M. Kumar Kumaran

Energy Conservation in Buildings and Community Systems Programme

INTERNATIONAL ENERGY AGENCY
Energy Conservation in Buildings and Community Systems

IEA ANNEX 24
Heat, Air and Moisture Transfer Through New and Retrofitted Insulated Envelope Parts (Hamtie)

Final Report

Volume 3

TASK 3: MATERIAL PROPERTIES

M. Kumar KUMARAN
Building Performance Laboratory
Institute for Research in Construction
National Research Council
Canada

COLOPHON

Author

M.K. Kumaran
Building Performance Laboratory
Institute for Research in Construction
National Research Council
Canada

Reviewer

Per Jostein Hovde
Department of Building and Constructrion Engineering
University of Trondheim
Norway

Publisher

Laboratorium Bouwfysica
Departement Burgerlijke Bouwkunde
K.U.-Leuven Belgium

Editor

Fatin Ali Mohamed
Laboratorium Bouwfysica
Belgium

© 1996

No part of this book may be reproduced in any form, by mimeograph, film or any other means without permission in writing from the publisher.

ISBN 90-75741-01-4

Print Acco Leuven

TABLE OF CONTENTS

1. CHAPTER 1: HEAT, AIR AND MOISTURE TRANSPORT THROUGH BUILDING MATERIALS AND COMPONENTS: SYMBOLS AND TERMINOLOGY 1

1.1 Introduction 1
1.2 Densities Of Flow Rates (Fluxes) 2
1.3 Material Properties 3
  1.3.1 References 8
1.4 List Of Symbols 9

2.CHAPTER 2: HYGROTHERMAL PROPERTIES OF COMMON BUILDING MATERIALS: A COMPILATION OF DATA FROM IEA ANNEX XXIV PARTICIPANTS 13

2.1 Concrete 14
2.2 Lightweight Concrete 20
2.3 Aerated Concrete 25
2.4 Brick 30
2.5 Cement Mortar 37
2.6 Gypsum Board 43
2.7 Pine 48
2.8 Spruce 53
2.9 Plywood 56
2.10 Wood Fibreboard 60
2.11 Wafer Board Or Wood-Chip Board 64
2.12 Particle Board 66
2.13 Polystyrene Concrete 69
2.14 Polymer-Modified Glassfibre Cement 70
2.15 Sand-Lime Stone 71
2.16 Wood Wool Cement Board 72
2.17 Fibre Cement 74
2.18 Glass Fibre Insulation 77
2.19 Mineral Fibre Insulation 82
2.20 Expanded Polystyrene Insulation 84
2.21 Cellulose Insulation 87
2.22 Extruded Polystyrene Insulation 90
2.23 Polyurethane Foam Insulation 94
2.24 Polyisocyanurate Foam Insulation 96
2.25 Phenolic Foam Insulation 98
2.26 Perlite Board 100
2.27 Feathers Of Chicken 102
2.28 Finishing Materials[1] 103
  2.28.1 Wall paper 103
  2.28.2 Wall Paint 103
  2.28.3 Carpet 104
  2.28.4 Timber Slabs 104
  2.28.5 Foils/ Vapour Barriers 105

APPENDIX I: REPORT ON MEASUREMENTS TO DETRMINE MOISTURE DIFFUSIVITY OF EASTERN WHITE PINE 109

APPENDIX II: REPORT ON ANALYTICAL METHODS TO DERIVE MOISTURE DIFFUSIVITY FROM TRANSIENT MOISTURE DISTRIBUTION 113

APPENDIX III: HYGROTHERMAL PROPERTIES OF BUILDING MATERIALS 123

APPENDIX IV: ANNOTATED LIST OF PAPERS DISCUSSED AT VARIUOS ANNEX XXIV MEETINGS 133

1. HEAT, AIR AND MOISTURE TRANSPORT THROUGH BUILDING MATERIALS AND COMPONENTS: SYMBOLS AND TERMINOLOGY

1.1 Introduction

The envelope of any building continuously responds to the changes in indoor and outdoor temperature, air pressure and humidity conditions. This results in an exchange of energy and mass (air as well as moisture) between the indoor and outdoor environments through the envelope. Building Physicists refer to this phenomena as "heat, air and moisture transport " through building materials and components. Designers and builders are always interested in knowing the long-term performance of the building envelope, as subjected to the transport processes. But the global differences in construction practices, building materials, weather conditions and indoor climate are so large that it is impractical to develop this knowledge only through experimental investigations. However, such knowledge, as and when required, can be generated through calculations. Building Physicists, over the past four or five decades, have been attempting to develop reliable calculation methods for this purpose. These attempts, especially with the advance in computer technology, have resulted in a diverse set of procedures and computer models. All such procedures, in spite of any diversity, make use of the following two axioms:

1. The transport of any entity B through a medium is given by the expression,
   Rate of transport of B = A property of the medium x
   A driving force responsible for the transport.

2. During the transport of B, in any given volume V of the medium, the following balance exists:
   Rate of storage of B in V = Rate of B entering V through its bounding surfaces +
   Rate of generation of B in V

The first axiom gives rise to a variety of equations used in calculations and these equations are called transport equations. They are usually of the form,

$$\dot{J}_B = k \bullet grad\, \Phi \qquad [1]$$

which introduces three types of physical quantities in all calculations. The quantity $\dot{J}_B$ is referred to as a "flux of B" or a "density of B flow rate" and the quantity κ as a transport property of the medium. The driving potential is defined as the gradient of an appropriate physical quantity Φ.

The second axiom, when used in calculations, introduces another set of equations called the "conservation equations". These equations in turn also introduce new physical quantities. The term on the left hand side of the balance equation results in physical quantities that define the storage of B in the medium. These are referred to as capacitive properties[1]. The first term on the right hand side of the balance equation, though only a divergent of JB, often may result in a set of derived physical quantities defined in terms of a transport property and a capacitive property. These properties are referred to as combined properties[1].

From the above discussion it follows that in the field of Building Physics that deals with simultaneous heat, air and moisture transport many physical quantities emerge. The purpose of this document is to assemble a set of terminology, symbols, units and definitions that forms the common " grammar and spelling" for the use of Building Physicists. The rest of this chapter is organized as a collection of entries, in two sections, with each entry corresponding to one physical quantity and including the name, symbol, unit and definition; with each entry, whenever necessary, appropriate comments are also included. The first section of these entries introduces the "densities of flow rates" and the second section the material properties.

1.2 Densities Of Flow Rates (Fluxes)

Density of heat flow rate (symbol: $\dot{q}$; unit: $W \cdot m^{-2}$)
The density of heat flow rate in a material at a point is expressed as the quantity of heat transported in unit time across unit area of a plane that includes the point and is perpendicular to the direction of the transport.

Density of Vapour Flow rate (symbol: $\dot{m}_v$; unit: $kg \cdot m^{-2} \cdot s^{-1}$)
The density of vapour flow rate in a material at a point is defined as the mass of vapour transported in unit time across unit area of a plane that includes the point and is perpendicular to the direction of the transport.

Density of Moisture Flow Rate (symbol: $\dot{m}_m$; unit: $kg \cdot m^{-2} \cdot s^{-1}$)
The density of moisture flow rate in a material at a point is defined as the mass of moisture transported in unit time across unit area of a plane that includes the point and is perpendicular to the direction of the transport.

Density of Air Flow Rate (symbol: $\dot{m}_a$; unit: $kg \cdot m^{-2} \cdot s^{-1}$)
The density of air flow rate in a material at a point is defined as the mass of air transported in unit time across unit area of a plane that includes the point and is perpendicular to the direction of the transport.

1.3 Material Properties

Density (symbol: ρ_0; unit: $kg \cdot m^{-3}$)
Density of a building material is defined as the mass of 1 m^3 of the dry material.

For practical reasons, the phrase "dry material" does not necessarily mean absolutely dry material. For each class of material, such as stony, wooden or plastic, it may be necessary to adopt prescribed standard conditions; for example for wood this may correspond to drying at 105 °C until the change in mass is within 1 % during two successive daily weighings.

Moisture Content (symbol(i): w; unit: $kg \cdot m^{-3}$) or
(symbol(ii): u; unit: $kg \cdot kg^{-1}$) or
(symbol(iii): ψ; unit: $m^3 \cdot m^{-3}$)
Moisture content of a building material is defined as:
i) mass of moisture per unit volume of the dry material or
ii) mass of moisture per unit mass of the dry material or
iii) volume of condensed moisture per unit volume of the dry material.

The definition (I) is generally used with reference to all building materials, while it is a common practice to use (ii) with reference to denser building materials such as concrete, brick and wood products and to use (iii) with reference to lighter materials such as insulation.

Many building materials are porous bodies. In these porous bodies the moisture content may vary between the dry state referred to above and a fully saturated state when the open pores are completely filled with water. The moisture content that corresponds to the saturation state is called the **maximum moisture content** (symbols: w_{max} or u_{max} or ψ_{max}). Experimentally, a building material absorbs moisture to the maximum moisture content level, if the process is carried out in vacuum. Otherwise, the saturation is complete at a lower moisture content level. This moisture content is referred to as **capillary saturation moisture content** (symbols: w_{cap} or u_{cap} or ψ_{cap}). Between the dry and saturated states, the moisture content varies with the water vapour pressure of the surroundings in a non-linear way. An example is shown in Figure 1. The relation between vapour pressure (or more often relative humidity, RH) of the surroundings and the moisture content in the material is called the **sorption curve**. In the lower humidity range , the moisture is in an adsorbed state. This range varies from material to material, and for certain materials could be up to 98 % RH. The range of RH until 98 % is called the **hygroscopic range** of a material. At the higher end of the adsorption range, moisture from the surroundings begins to condense in the pores, but initially without any continuity of the liquid at a macroscopic level. This continues until a **critical moisture content** (symbols: w_{cr} or u_{cr} or ψ_{cr}) is established. Thus critical moisture content can be defined as the lowest moisture content necessary to initiate moisture transport in the liquid phase. Below this level, due to macroscopic discontinuity of the liquid, moisture is transported only in the vapour phase (and partly by surface movement in the adsorbed layer).

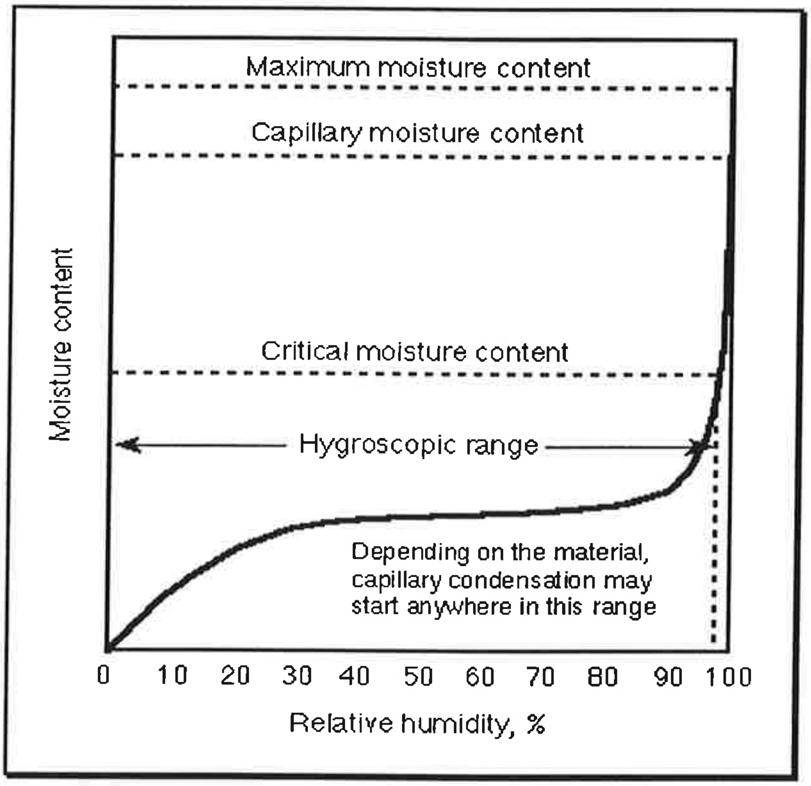

Figure 1: Sorption isotherm of a porous building material.

Degree of Saturation (Symbol: S; unit: dimensionless)
The degree of saturation of a material at a given moisture content is defined as the ratio between that moisture content and the maximum moisture content that can be attained by the material.

Specific Heat Capacity (Symbol: c_o; unit: $J{\cdot}kg^{-1}{\cdot}K^{-1}$)
Specific heat capacity of a material is defined as the heat (energy) required to increase the temperature of unit mass of the material by 1 K.

The mass in the above definition refers to dry mass. If the material is wet, the specific heat capacity c is to be calculated as:

$$c = c_o + 4187 \bullet (w/\rho_o) \qquad [2]$$

The above relation assumes that the specific heat capacity of water is a constant equal to 4187 $J{\cdot}kg^{-1}{\cdot}K^{-1}$.

Volumetric Heat Capacity (Symbol: $\rho_o c_o$; unit: $J{\cdot}m^{-3}{\cdot}K^{-1}$)

The volumetric heat capacity of a material is defined as the heat (energy) required to increase the temperature of unit volume of the material by 1 K.

If the material is wet , the volumetric heat capacity $\rho_o c$ is calculated as:

$$\rho_o c = \rho_o c_o + 4187 \bullet w \qquad [3]$$

The equations (2) and (3) assume that the heat capacity of water is constant at 4187 $J \cdot kg^{-1} \cdot K^{-1}$.

Thermal Conductivity (Symbol:λ; unit: $W \cdot m^{-1} \cdot K^{-1}$)
The thermal conductivity of a material at a point is defined as the ratio between the density of heat flow rate and the magnitude of the thermal gradient at that point in the direction of the flow.

The definition for thermal conductivity stems from Fourier equation for heat conduction:

$$\dot{q} = - \lambda \bullet grad\, T \qquad [4]$$

But in a dry building material the heat transfer is a resultant of conduction, radiation from the surfaces of the pores and convection within the pores and in a practical definition of thermal conductivity all three modes of heat transfer are included. If the material is wet, heat transferred by moisture in the capillaries and the enthalpy changes that accompany phase transitions also add to the density of heat flow rate.

Thermal Resistance (Symbol: R; unit: $K \cdot m^2 \cdot W^{-1}$)
The thermal resistance of a specimen of a material bound by two parallel surfaces is defined as the ratio between the magnitude of the temperature difference across the two bounding surfaces and the density of heat flow rate across the specimen under a steady state condition.

Thermal Diffusivity (Symbol: a; unit: $m^2 \cdot s^{-1}$)
The thermal diffusivity at a point in a material is defined as the ratio between the thermal conductivity at that point and the volumetric heat capacity of the material.

Vapour concentration (Symbol: ρ_v; unit: $kg.m^{-3}$)
The vapour concentration in a given volume of a building material is defined as the ratio between the mass of water vapour in that volume and the volume. It can also be defined as the mass of water vapour per unit volume of the material.

Vapour Permeability (Symbol: δ_p; unit: $kg.m^{-1} \cdot Pa^{-1} \cdot s^{-1}$)
The vapour permeability at a point is defined as the ratio between the density of vapour flow rate at that point and the magnitude of the vapour pressure gradient in the direction of the flow.

The definition for vapour permeability stems from the transport equation:

$$\dot{m}_v = -\delta_p \bullet grad\, p_v \qquad [5]$$

Among all the moisture transport properties, the vapour permeabilities of building materials are most readily measurable, by use of the "cup method". Various data reported in the literature show that for most of the hygroscopic materials, the vapour permeability is a strong function of the mean relative humidity of the material.

For practical purposes a quantity called **vapour permeance** (Symbol: δ_l; unit: $kg \cdot m^{-2} \cdot Pa^{-1} . s^{-1}$) of a specimen of a building material is useful. This quantity is defined as follows:

> The vapour permeance of a specimen of a material bound by two parallel surfaces is the ratio between the density of vapour flow rate and the magnitude of the vapour pressure difference across the bounding surfaces, under steady state conditions.

The reciprocal of vapour permeability is **vapour resistivity** (Symbol: N; unit: $m \cdot Pa \cdot s \cdot kg^{-1}$) and that of vapour permeance is called **vapour resistance**(Symbol: Z_p; unit: $m^2 \cdot Pa \cdot s \cdot kg^{-1}$)

If the vapour transport equation is written as:

$$\dot{m}_v = -\delta_v \cdot grad\, \rho_v \qquad [6]$$

the **vapour permeability** (Symbol: δ_v; unit: $m^2 \cdot s^{-1}$) at a point is defined as the ratio between the density of vapour flow rate at that point and the magnitude of the vapour concentration gradient in the direction of the flow.

Vapour Resistance Factor (Symbol: μ; unit: dimensionless)
The vapour resistance factor of a material is defined as the ratio between the vapour permeability of stagnant air, δ_a, and that of the material under identical thermodynamic conditions (same temperature and pressure). The vapour permeability of stagnant air can be calculated according to the equation given by Schirmer[2] in agreement with more recent work by Fuller et al, as reported in reference 3.
Schirmer's equation is given below:

$$d_a = \frac{2.306x10^{-5} P_o}{R_v TP} \left(\frac{T}{273.15}\right)^{1.81} \qquad [7]$$

Where,
T = temperature (K)
P = ambient pressure (Pa)
P_o = standard atmospheric pressure, ie. 101325 Pa
R_v = ideal gas constant for water, ie. 461.5 $J \cdot K^{-1} \cdot kg^{-1}$.

The concept of vapour resistance factor introduces two physical quantities that describe the pore structure of the building material. By definition, μ for stagnant air is 1. If in a slab of dry material, the pores connect two parallel bounding surfaces of the material straight across and each pore is uniform with respect to the cross sectional area, then:

$$\mu = 1/\psi_O \qquad [8]$$

where ψ_o is called the **open porosity** (unit: $m^3 \cdot m^{-3}$) which refers to the volume of pores per unit volume of the material, accessible for water vapour.

If the pores are non-uniform and are directed randomly,

$$\mu = (\psi_\tau / \psi_O) \qquad [9]$$

where ψ_τ is called the **tortuosity factor**.

Vapour Diffusion Thickness (Symbol: μd; unit: m)
Vapour diffusion thickness of a specimen is the product of its thickness and the vapour resistance factor of the material.

Moisture Permeability (Symbol: k_m; unit: $kg.m^{-1} \cdot Pa^{-1} \cdot s^{-1}$)
Moisture permeability of a material at a point in a direction is defined as the ratio between the density of moisture flow rate at that point and the magnitude of suction gradient in the direction of the flow.

Suction includes capillarity, gravity and external pressure. The definition for moisture permeability stems from the transport equation:

$$\dot{m}_m = -k_m \cdot grad\ s \qquad [10]$$

where s is the total suction (unit: Pa); then for capillarity suction, s includes the pore liquid pressure and for gravity it includes the product of acceleration of free fall, density of water and height. The sorption curve in the region above the critical moisture content includes the suction. But it is not particularly evident. Hence it is practical to construct a curve which represents the relation between moisture content and pore size distribution. Then the full moisture content range can be divided into two - the first range up to the critical moisture content in the form of a sorption curve and the second from critical moisture content up to maximum moisture content in the form of a suction curve.

Specific Moisture Capacity (symbol: ξ; unit: $kg \cdot kg^{-1} \cdot Pa^{-1}$)
Specific moisture capacity of a material is defined as the increase in the mass of moisture in unit mass of the material that follows unit increase in vapour pressure or suction.
If the vapour pressure is expressed in terms of relative humidity the unit of this quantity changes to $kg.kg^{-1}$ and then the symbol ξ_φ should be used.

Volumetric Moisture Capacity (symbol: $\rho_o\xi$; unit: $kg \cdot m^{-3} \cdot Pa^{-1}$)
The volumetric moisture capacity of a material is defined as the increase in the moisture content in unit volume of the material that follows unit increase in the vapour pressure or suction.
For hygroscopic range volumetric moisture capacity can be calculated from the slope of the sorption curve and above critical moisture content it can be calculated as the slope of the suction curve.

Moisture Diffusivity (symbol: D_w; unit: $m^2 \cdot s^{-1}$)
The moisture diffusivity in the hygroscopic range is the ratio between vapour permeability and volumetric moisture capacity. Outside that range it is the ratio between moisture permeability and volumetric moisture capacity.

The above definition is analogous to that for thermal diffusivity. However, moisture diffusivity is currently used according to the following definition for the density of moisture flow rate:

$$\dot{m}_m = - \rho_0 D_w \bullet grad\, u \qquad [12]$$

Thermal Moisture Permeability (symbol: k_T; unit: $kg \cdot m^{-1} \cdot K^{-1} \cdot s^{-1}$)
The thermal moisture permeability of a material at a point is defined as the ratio between the density of moisture flow rate at that point and the magnitude of temperature gradient in the direction of the transport in the absence of any moisture content gradient.
The above definition for thermal moisture permeability stems from the transport equation:

$$\dot{m}_m = - k_T \bullet grad\, T \text{ (at uniform moisture content)} \qquad [13]$$

Thermal Moisture Diffusion Coefficient (symbol: D_T; unit: $m^2 \cdot K^{-1} \cdot s^{-1}$)
The ratio between the dry density and thermal moisture permeability is called the thermal moisture diffusion coefficient. Therefore, equation (11) can also be written as:

$$\dot{m}_m = - \rho_0 D_T \bullet grad\, T \text{ (at uniform moisture content)} \qquad [12]$$

Air Permeability (Symbol: k_a; unit: $kg \cdot m^{-1} \cdot Pa^{-1} \cdot s^{-1}$)
The air permeability of a material at a point is defined as the ratio between the density of air flow rate at that point and the magnitude of the pressure gradient in the direction of the flow.
For practical purposes a quantity called **air permeance** (Symbol: K_a; unit: $kg \cdot m^{-2} \cdot Pa^{-1} \cdot s^{-1}$) of a specimen of a building material is useful. This quantity is defined as follows:
The air permeance of a specimen of a material bound by two parallel surfaces is the ratio between the density of air flow rate and the magnitude of the pressure difference across the bounding surfaces, under steady state conditions.

In addition to the quantities defined in this document there are a number of other physical quantities that Building Physicists use. These can be found in the enclosed list of symbols.

1.3.1 References

1. IEA-ANNEX XIV: Condensation and Energy. Volume 1 Source book, Chapter 1: Material Properties.
2. Schirmer, R. ZVDI, Beiheft Verfahrenstechnik (1938), Nr. 6, S.170.
3. Reid, R., J. M. Prausnitz and B. E. Poling. The Properties of Gases and Liquids. Fourth Edition, McGraw-Hill, 1987, p.587.

1.4 List Of Symbols

SYMBOL	PHYSICAL QUANTITY	UNIT
a	absorptivity	-
a	thermal diffusivity	$m^2 \cdot s^{-1}$
b	thermal effusivity	$J \cdot m^{-2} \cdot K^{-1} \cdot s^{-1/2}$
co	specific heat capacity of a dry material	$J \cdot kg^{-1} \cdot K^{-1}$
c	specific heat capacity of a wet material	$J \cdot kg^{-1} \cdot K^{-1}$
d	thickness	m
dh	hydraulic diameter	m
e	emissivity	-
f	friction factor	-
g	acceleration of free fall	$m \cdot s^{-2}$
h	specific enthalpy	$J \cdot kg^{-1}$
he	specific enthalpy of evaporation	$J \cdot kg^{-1}$
hm	specific enthalpy of melting	$J \cdot kg^{-1}$
ka	air permeability	$kg \cdot m^{-1} \cdot Pa^{-1} \cdot s^{-1}$ (s)
km	moisture permeability	$kg \cdot m^{-1} \cdot Pa^{-1} \cdot s^{-1}$ (s)
kT	thermal moisture permeability	$kg \cdot m^{-1} \cdot K\text{-}1 \cdot s^{-1}$
l	length	m
m	mass	kg
$\dot{m}$	density of mass flow rate	$kg \cdot m^{-2} \cdot s^{-1}$
n	ventilation rate	h^{-1}
p	water vapour pressure	Pa

SYMBOL	PHYSICAL QUANTITY	UNIT
pc	capillary suction	Pa
psat	saturation water vapour pressure	Pa
$\dot{q}$	density of heat flow rate	$W \cdot m^{-2}$
r	reflectivity	-
s	total suction	Pa
t	time	s
u	moisture content(mass by mass)	$kg \cdot kg^{-1}$
v	velocity	$m \cdot s^{-1}$
w	moisture content(mass by volume)	$kg \cdot m^{-3}$
x	water vapour ratio (mass by mass)	$kg \cdot kg^{-1}$
x,y,z	spatial coordinates	m
A	water sorption coefficient	$kg \cdot m^{-2} \cdot s^{-1/2}$
A	area	m^2
B	water penetration coefficient	$m.s^{-1/2}$
DT	thermal moisture diffusion coefficient	$m^2 \cdot K^{-}1 \cdot s^{-1}$
D_w	moisture diffusivity	$m^2 \cdot s^{-1}$
H	enthalpy	J
Ka	air permeance	$kg \cdot m^{-2} Pa^{-1} \cdot s^{-1} (s \cdot m^{-1})$
N	vapour resistivity	$m \cdot Pa \cdot s \cdot kg^{-1}$

SYMBOL	PHYSICAL QUANTITY	UNIT
$\dot{M}$	mass flow rate	$kg.s^{-1}$
Q	quantity of heat	J
$\dot{Q}$	heat flow rate	W
R	thermal resistance	$K \cdot m^2 \cdot W^{-1}$

SYMBOL	PHYSICAL QUANTITY	UNIT
R	gas constant	$J \cdot kg^{-1} \cdot K^{-1}$
S	degree of saturation	-
T	thermodynamic temperature	K
U	thermal permeance	$W \cdot m^{-2} \cdot K^{-1}$
V	volume	m^3
Z_p	vapour resistance related to vapour pressure gradient	$Pa \cdot m^2 \cdot s \cdot kg^{-1}$ $(m \cdot s^{-1})$
Z_v	vapour resistance related to vapour concentration gradient	$s \cdot m^{-1}$
α	surface film coefficient for heat transfer	$W \cdot m^{-2} \cdot K^{-1}$
β_p	surface film coefficient for diffusion related to vapour pressure gradient	$s \cdot m^{-1}$
β_v	surface film coefficient for diffusion related to vapour concentration gradient	$m \cdot s^{-1}$
δ_p	vapour permeability related to vapour pressure gradient	s
δ_v	vapour permeability related to vapour concentration gradient	$m^2 \cdot s^{-1}$
$\in$	strain	-
$\in_T$	specific heat strain	K^{-1}
$\in_u$	specific hygric strain	$kg \cdot kg^{-1}$
ε	surface roughness	m

SYMBOL	PHYSICAL QUANTITY	UNIT
ζ	hydraulic loss factor	-
η	dynamic viscosity	$N \cdot s \cdot m^{-2}$
θ	temperature	°C
λ	thermal conductivity	$W \cdot m^{-1} \cdot K^{-1}$
μ	vapour resistance factor	-
μd	vapour diffusion thickness	m
ν	kinematic viscosity	$m^2 \cdot s^{-1}$
ξ	specific moisture capacity	$kg \cdot kg^{-1} \cdot Pa^{-1}$
ξ_{φ}	specific moisture capacity in terms of relative humidity	$kg \cdot kg^{-1}$
ρ	density	$kg \cdot m^{-3}$
ρ_v	water vapour concentration	$kg \cdot m^{-3}$
ρc	volumetric heat capacity	$J \cdot m^{-3} \cdot K^{-1}$
$\rho \xi$	volumetric moisture capacity	$kg \cdot m^{-3} \cdot Pa^{-1}$
$\rho \xi_{\varphi}$	volumetric moisture capacity in terms of RH	$kg \cdot m^{-3}$

SYMBOL	PHYSICAL QUANTITY	UNIT
σ	surface tension	$N \cdot m^{-1}$
τ	transmissivity	-
τ	temperature ratio	-
φ	relative humidity	-
ψ	moisture content volume by volume	$m^3 \cdot m^{-3}$
ψ_a	air content	$m^3 \cdot m^{-3}$
ψ_o	open porosity	$m^3 \cdot m^{-3}$

SUBSCRIPTS

a	air	i	ice
a	ambient	l	liquid
abs	absorption	m	moisture
cap	capillary	m	melting
c	convective	max	maximum
cr	critical	o	dry material
des	desorption	p	pressure
e	exterior	r	radiation
e	evaporation	s	surface
eff	effective	sat	saturation
eq	equivalent	v	vapour
h	hygroscopic	vac	vacuum
i	interior	w	water

2. HYGROTHERMAL PROPERTIES OF COMMON BUILDING MATERIALS: A COMPILATION OF DATA FROM IEA ANNEX XXIV PARTICIPANTS

Preface

The lists of material properties presented in this chapter are compiled mainly from the data collected from all the 14 countries that participated in the Annex. Special data sheets were developed for this purpose and distributed to all participating countries to make their input. Also, the "Catalogue of Material Properties" that resulted from the Annex 14 activities and a few technical publications, theses and official reports from various organizations were used for the present compilation. Each of the following sections in this chapter starts with a listing of the sources from which the data are retrieved. Whenever possible, the densities, thickness etc. of the test specimens are included in the source.

2.1 Concrete

- **Sources**

[1] Catalogue of Material properties(upgraded version), Report Annex XIV, Page 2.2

[2] Laboratoire de Thermique des Materiaux et des Batiments, INSA, Toulouse France data, Beton Siliceux, density of specimen 2270 kg·m^{-3}

[3] Laboratory of Building Physics, KU-Leuven, Belgium, data;density of specimen 2180 kg·m^{-3} and thickness 90 mm, 7 year old.

[4] Laboratoire de Thermique des Materiaux et des Batiments, INSA, Toulouse France, Beton Siliceux, density of specimen 2270 kg·m^{-3}, mean temperature -10 to 60 °C.

[5] Norwegian Building Research Institute and Norwegian Institute of Technology, Trondheim, Norway, data, dry material at 20 °C.

[5a] Institute for Reseach in Construction, Data; density of the specimens 2164 and 2146Kg·m^{-3}

[6] Kurt Kielsgaard Hansen, Sorption Isotherms, A Catalogue, The Technical University of Denmark, Technical Report 162/86; the data corresponds to a concrete sample with the following specifications: Concrete K 300 P, C = 320 kg·m^{-3}, std, w/c = 0.48, wn/c = 0.20, lo = 3.9 %, max size of stones = 32 mm; the data originally appeared in Tech. Report 36, Lund Inst. of Technology by Ahlgren Lennart, 1972. Hansen's Catalogue lists the sorption/desorption curves for concrete samples with w/c ratio between 0.04 and 0.72. These values are not significantly different from those in the table below.

[7] Galbraith G. H., McLean, R. C.' Vapour permeability testing', Final report to the Building Research Establishment; Contract F3/2/490, Strathclyde University, June 1993.

[8] Fraunhofer Institute of Building Physics, Holzkirchen, Germany, data.

[9] Goran Hedenblad, Lund University Doctoral Dissertation, Moisture Permeability of Mature Concrete, Cement Mortar and Cement Paste, 1993.

• **Dry density:**	2200 ± 100 kg·m^{-3}
• **Heat capacity:**	840 J·kg^{-1}·K^{-1}[1] 940 J·kg^{-1}·K^{-1}[2]
• **Porosity:**	≈ 0.15 m^{3}·m^{-3}[2]

- **Thermal conductivity of the dry material:**

Test Method	T, Hot surface °C	T, Cold surface °C	λ $W \cdot m^{-1} \cdot K^{-1}$
B62-003	11.5	9.0	2.0[3]
"	22.4	18.9	2.0[3]
"	32.9	29.4	2.0[3]
***	***	***	1.16[4]
***	***	***	1.7[5]
ASTM C518	33.81	20.62	1.21[5a]
"	33.38	20.53	1.26[5a]

- **Thermal conductivity of moist material at 0 °C[2]:**

moisture content $kg \cdot kg^{-1}$	λ $W \cdot m^{-1} \cdot K^{-1}$	moisture content $kg \cdot kg^{-1}$	λ $W \cdot m^{-1} \cdot K^{-1}$
0	1.16	0.04	2.61
0.01	1.89	0.05	2.71
0.02	2.24	0.06	2.78
0.03	2.46	***	***

Reference[1] gives the following equation, at 20 °C:

$$\lambda\ (W \cdot m^{-1} \cdot K^{-1}) = 2.74 + 0.0032\, w,$$

where w is the moisture content ($kg \cdot m^{-3}$).

- **Sorption/desorption curve[6]:**

Relative humidity %	Sorption moisture content $kg \cdot kg^{-1}$	Desorption moisture content $kg \cdot kg^{-1}$
25	0.0094	
25.5	0.0083	
44.7	0.0122	
45.1	0.0109	
64.8	0.0182	
65.2	0.0 165	
79.8	0.0268	
80.2	0.0256	
89.6	0.0345	
90.1	0.0325	
97.8	0.0425	
98.5	0.0462	
19.9		0.0100
20.2		0.0088

Relative humidity %	Sorption moisture content $kg \cdot kg^{-1}$	Desorption moisture content $kg \cdot kg^{-1}$
45.1		0.0226
45.7		0.0212
65.3		0.0305
65.8		0.0290
84.6		0.0375
84.9		0.0395
94.7		0.0467
95.0		0.0447

Reference[1] gives the following equations for sorption:

$$w(kg \cdot m^{-3}) = 147.5[1 - \ln \varphi / 0.0453]^{-1/1.67} \text{ or}$$
$$= \varphi / (-0.069\, \varphi^2 + 0.081\, \varphi - 0.004)$$

Reference[1] gives the following equations for desorption:

$$w(kg \cdot m^{-3}) = 147.5[1 - \ln \varphi / 0.570]^{-1/0.64} \text{ or}$$
$$= \varphi / (0.018\, \varphi^2 - 0.027\, \varphi + 0.020)$$

The relative humidity, φ in the above equations is expressed as a fraction.

- **Capillary moisture content:** ≈ 110 $kg \cdot m^{-3}$[1]
- **Saturation moisture content:** ≈ 150 $kg \cdot m^{-3}$[1]
  158 $kg \cdot m^{-3}$[2]

- **Water Vapour Permeability (from cup method):**

RH(1) %	RH(2) %	Mean RH %	Water vapour permeability at 23 °C $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1} \times 10^{-12}$
0	60		6.13[7]
60	80		6.76[7]
60	93		7.61[7]
60	100		10.8[7]
3	50		1.2[8]
3	50		1.4[8]
		25	1.26[2]
		50	1.4[2]
		75	2.5[2]
		95	6.3[2]

Reference[1] gives the following equation for the vapour resistance factor, μ

$\mu = 1/[6.8 \times 10^{-3} + 8.21 \times 10^{-5} \exp(5.66\varphi)]$ with relative humidity φ expressed as a fraction.

Desorption Isotherms and Water vapour permeabilities of approximately 5 year old concrete samples[9]

Sample 1. Composition: Cement = 418 $kg \cdot m^{-3}$; Water = 167 $kg \cdot m^{-3}$; Sand = 990 $kg \cdot m^{-3}$; Macadam = 910 $kg \cdot m^{-3}$.

RH %	Moisture Content $kg \cdot m^{-3}$	RH %	Water Vapour Permeability $kg \cdot m^{-1} \cdot Pa^{-1} \cdot s^{-1}$
30	39	30	1.0E-12
50	49	65	1.0E-12
60	59	70	1.4E-12
70	69	80	2.1E-12
80	80	84	2.6E-12
86	88	88	3.4E-12
90	95	90	3.9E-12
92	100	93	4.4E-12
94	105	96	5.2E-12
96	111		

Sample 2. Composition: Cement = 368 $kg \cdot m^{-3}$; Water = 184 $kg \cdot m^{-3}$; Sand = 990 $kg \cdot m^{-3}$; Macadam = 910 $kg \cdot m^{-3}$.

RH %	Moisture Content $kg \cdot m^{-3}$	RH %	Water Vapour Permeability $kg \cdot m^{-1} \cdot Pa^{-1} \cdot s^{-1}$
30	37	30	1.0E-12
50	48	65	1.0E-12
65	65	80	2.4E-12
75	78	86	4.4E-12
84	91	90	7.4E-12
90	101	93	1.3E-11
93	108	95	2.1E-11
95	114	96	3.1E-11
96	119	97	6.7E-11
97	129		

Sample 3. Composition: Cement = 328 kg·m^{-3}; Water = 197 kg·m^{-3}; Sand = 990 kg·m^{-3}; Macadam = 910 kg·m^{-3}.

RH %	Moisture Content kg·m^{-3}	RH %	Water Vapour Permeability kg·m^{-1}·Pa^{-1}·s^{-1}
30	34	30	1.3E-12
65	63	65	1.3E-12
80	85	80	2.8E-12
86	97	86	5.4E-12
90	107	90	1.1E-11
93	114	93	2.4E-11
95	122	95	5.6E-11
96	128	96	6.3E-11
97	138	97	1.0E-10
97.6	144	97.6	1.6E-10

Sample 4. Composition: Cement = 296 kg·m^{-3}; Water = 207 kg·m^{-3}; Sand = 990 kg·m^{-3}; Macadam = 910 kg·m^{-3}.

RH %	Moisture Content kg·m^{-3}	RH %	Water Vapour Permeability kg·m^{-1}·Pa^{-1}·s^{-1}
30	32	30	1.3E-12
65	61	65	1.3E-12
80	85	80	2.8E-12
86	99	86	5.4E-12
90	111	90	1.1E-11
93	121	93	2.4E-11
95	131	95	5.6E-11
97	148	97	1.3E-10
97.6	155	97.6	2.1E-10
98	160	98	2.8E-10

- **Moisture diffusivity**[2]:

Moisture content ($kg \cdot kg^{-1}$)	**Moisture diffusivity ($m^2 \cdot s^{-1}$)**
0.0066	1.44E-11
0.011	1.56E-11
0.0154	1.75E-10
0.022	2.89E-10
0.0286	2.89E-10
0.0352	2.89E-10
0.0418	2.89E-10
0.0484	2.89E-10
0.069	2.89E-10

Reference[1] gives the following equation for moisture diffusivity, D_W:

$$D_W\ (m^2 \cdot s^{-1}) = 1.8 \times 10^{-11} \exp(0.0582\, w)$$

where w is the moisture content expressed in $kg \cdot m^{-3}$.

- **Suction curve**[2] **at 10 °C :**

P, Pa	1×10^9	4×10^8	2.3×10^8	1.7×10^8	1.4×10^8	1.1×10^8
u, $kg \cdot kg^{-1}$	0	0.007	0.014	0.021	0.028	0.035

P, Pa	9.1×10^7	7.2×10^7	6×10^7	2.8×10^7	2.1×10^6	1.0×10^4
u, $kg \cdot kg^{-1}$	0.042	0.049	0.056	0.063	0.067	0.069

- **Thermal moisture diffusion coefficient at 20 °C as a function of moisture content**[2]**:**

u, ($kg \cdot kg^{-1}$)	0.066	0.011	0.015	0.022	0.029	0.035	0.042	0.048
D_T, ($m^2 \cdot s^{-1} \cdot K^{-1}$) x 10^{-13}	1.28	4.48	8.4	13.1	14.7	14.0	12.0	1.8

- **Water Absorption Coefficient**[1]**:** 0.018 $kg \cdot m^{-2} \cdot s^{-1/2}$
- **Air permeability**[5]**:** 1 x 10^{-3} $m^3 \cdot m^{-1} \cdot h^{-1} \cdot Pa^{-1}$

2.2 Lightweight Concrete

- **SOURCES**

[1] Catalogue of Material properties (upgraded version), Report Annex XIV, Page 2.2

[2] Laboratoire de Thermique des Materiaux et des Batiments, INSA, Toulouse France, data, Beton, density of specimen 1600 kg·m^{-3}

[3] Laboratory of Building Physics, KU-Leuven, Belgium, data; density of specimen 1296 kg·m^{-3} and thickness 70.5 mm.

[4] Norwegian Building Research Institute and Norwegian Institute of Technology, Trondheim, Norway, data, dry material at 20 °C with density between 600 to 1300 kg·m^{-3}.

[5] Kurt Kielsgaard Hansen, Sorption Isotherms, A Catalogue, The Technical University of Denmark, Technical Report 162/86; the data corresponds to a concrete sample with the following specifications: density = 640 kg·m^{-3}, open porosity = 0.47 m^3·m^{-3}; the data originally appeared in Tech. Report 36, Lund Inst. of Technology by Ahlgren Lennart, 1972.

[6] Galbraith G. H., McLean, R. C.' Vapour permeability testing', Final report to the Building Research Establishment; Contract F3/2/490, Strathclyde University, June 1993; dry density 1327 kg·m^{-3}.

[7] Fraunhofer Institute of Building Physics, Holzkirchen, Germany, data; light concrete with expanded concrete; density between 1080 and 1420 kg·m^{-3}.

- **Dry density:** 600 to 1600 kg·m-3

- **Heat capacity:** 840 J·kg^{-1}·K^{-1}[1,2]
  900 J·kg^{-1}·K^{-1}[4]

- **Porosity**: ≈ 0.51 m^3·m^{-3}[3], density 1296 kg.m^{-3}
  ≈ 0.33 m^3·m^{-3}[2], density 1600 kg·m^{-3}

- **Thermal conductivity of the dry material:**

Test Method	T,Hot surface °C	T, Cold surface °C	Temperature °C	λ W·m^{-1}·K^{-1}
B62-003	13.8	6.6		0.588[3]
"	23.6	16.6		0.588[3]
"	33.6	26.7		0.593[3]
***	***	***	0	0.36[2]
***	***	***	20	0.367[2]
			60	0.374[2]
***	***	***	20	0.2 to 0.28[4]

Reference[1] gives the following equation for the thermal conductivity of the dry material as a function of the density ρ, between 644 and 1187 $kg \cdot m^{-3}$, at 20 °C:

$$\lambda = 0.0414 \exp(0.00205\ \rho)$$

- **Thermal conductivity of moist material at 20 °C[2]:**

moisture content $kg \cdot kg^{-1}$	**λ $W \cdot m^{-1} \cdot K^{-1}$**	**moisture content $kg \cdot kg^{-1}$**	**λ $W \cdot m^{-1} \cdot K^{-1}$**
0	0.367	0.16	0.716
0.008	0.459	0.24	0.80
0.04	0.514	0.32	0.873
0.08	0.613	***	***

Reference[1] gives the following equations, at 20 °C:

$\lambda\ (W \cdot m^{-1} \cdot K^{-1}) = 0.511 + 0.00255\ w$, dry density between 1158 and 1187 $kg \cdot m^{-3}$
$\lambda\ (W \cdot m^{-1} \cdot K^{-1}) = 0.371 + 0.00104\ w$, dry density between 1130 and 1138 $kg \cdot m^{-3}$
$\lambda\ (W \cdot m^{-1} \cdot K^{-1}) = 0.161 + 0.00150\ w$, dry density between 644 and 674 $kg \cdot m^{-3}$

where w is the moisture content ($kg \cdot m^{-3}$).

- **Sorption/desorption curve[5]:**

Relative humidity %	**Sorption moisture content $kg \cdot kg^{-1}$**	**Desorption moisture content $kg \cdot kg^{-1}$**
25	0.027	
25.2	0.030	
45.2	0.032	
45.6	0.034	
65.2	0.039	
65.5	0.041	
85.1	0.050	
85.3	0.052	
95.5	0.077	
95.8	0.079	
98.1	0.093	
98.5	0.095	
19.6		0.027
20.1		0.029
40.2		0.047
40.4		0.047
60.1		0.061
60.7		0.057
80.1		0.075

Relative humidity %	**Sorption moisture content** $kg \cdot kg^{-1}$	**Desorption moisture content** $kg \cdot kg^{-1}$
80.5		0.073
95.0		0.105
95.2		0.105

- **Sorption/desorption curve[5]:**

Relative humidity %	**Sorption moisture content** $kg \cdot kg^{-1}$	**Desorption moisture content** $kg \cdot kg^{-1}$
24.3	0.030	
24.5	0.028	
44.9	0.033	
45.4	0.034	
65.1	0.039	
65.3	0.041	
84.8	0.050	
85.1	0.043	
97.8	0.064	
98.1	0.069	
19.4		0.032
19.9		0.030
39.7		0.045
40.4		0.044
59.5		0.050
60.0		0.054
79.5		0.061
79.8		0.058
94.5		0.069
94.9		0.073

Reference[1] gives the following equations for sorption:
$w(kg \cdot m^{-3}) = 110[1 - \ln \varphi / 0.0227]^{-1/2.14}$ or
$= \varphi / (-0.047 \varphi^2 + 0.055 \varphi + 0.006)$

Reference[1] gives the following equations for desorption:
$w(kg \cdot m^{-3}) = 115[1 - \ln \varphi / 0.0221]^{-1/2.91}$ or
$= \varphi / (0.034 \varphi^2 - 0.038 \varphi + 0.022)$

The dry density of the material is between 938 and 1442 $kg \cdot m^{-3}$.

- **Capillary moisture content:** 97 to 190 $kg \cdot m^{-3}$[1]; density between 872 and 980 $kg \cdot m^{-3}$.

- **Saturation moisture content:** ≈ 580 kg·m^{-3}[1]; density 973 kg·m^{-3} .

- **Water Vapour Permeability (from cup method):**

RH(1) **%**	**RH(2)** **%**	**Mean RH** **%**	**Water vapour permeability at 23 °C** **kg·m^{-1}·s^{-1}·Pa^{-1} x 10 $^{-11}$**
0	60		1.23[6]
60	80		1.14[6]
60	93		1.66[6]
60	100		1.87[6]
3	50		0.34[7]
3	50		0.26[7]

Reference[1] gives the following equation for the vapour resistance factor, μ

$\mu = 1/[6.76 \text{ x } 10^{-2} + 1.21 \text{ x } 10^{-3} \exp(3.94\varphi)]$ with relative humidity φ expressed as a fraction, the density of the material being 975 kg·m^{-3}.

- **Moisture diffusivity**[2]:

Moisture content (kg•kg^{-1})	**Moisture diffusivity (m^2·s^{-1})**
0.01	1.5E-08
0.03	2.4E-08
0.08	4.9E-08
0.12	7.5E-08
0.16	1.8E-07
0.18	2.7E-07
0.20	4.51E-07
0.22	5.1E-07

Reference[1] gives the following equation for moisture diffusivity, D_W:

D_W (m^2·s^{-1}) = $1.3 \text{ x } 10^{-9} \exp(0.0351\, w)$

where w is the moisture content expressed in kg·m^{-3} , the density of the material 975 kg·m^{-3}.

- **Suction curve**[2] **at 20 °C :**

P, Pa	$1\text{x}10^9$	$2.2\text{x}10^6$	$3.0\text{x}10^5$	$1.3\text{x}10^5$	$1.0\text{x}10^5$	$7.0\text{x}10^4$
u,kg•kg^{-1}	0	0.0022	0.0044	0.0077	0.0154	0.055

P , Pa	4.5×10^4	3.5×10^4	2.4×10^4	5.0×10^3
u, kg•kg^{-1}	0.11	0.165	0.198	0.218

- **Thermal moisture diffusion coefficient at 20 °C as a function of moisture content[2]:**

u, (kg•kg^{-1})	0.01	0.03	0.08	0.12	0.16	0.18	0.20	0.22
D_T, (m^2 ·s^{-1}·K^{-1}) x 10^{-7}	0.15	0.24	0.49	0.75	1.8	2.72	4.51	5.1

- **Water Absorption Coefficient[1]:** 0.08 kg·m^{-2}·s$^{-½}$; density being 975 kg·m^{-3}.
  0.029 kg·m^{-2}·s$^{-½}$; density being 1410 kg·m^{-3}.

- **Air permeability[4]:** 0.8 m^3·m^{-1}·h^{-1}·Pa^{-1}

2.3 Aerated Concrete

- **SOURCES**

[1] Catalogue of Material properties(upgraded version), Report Annex XIV, Page 2.4

[2] Laboratoire de Thermique des Materiaux et des Batiments, INSA, Toulouse France, data, Beton Cellulaire, density of specimen 700 kg·m^{-3}

[3] Institute of Construction and Architeture of SAS, Department of Building Physics, Slovakia, data.

[4] Norwegian Building Research Institute and Norwegian Institute of Technology, Trondheim, Norway, data, dry material at 20 °C with density 500 kg·m^{-3}.

[5] Kurt Kielsgaard Hansen, Sorption Isotherms, A Catalogue, The Technical University of Denmark, Technical Report 162/86; the data corresponds to a cellular concrete sample with a density = 500 kg·m^{-3}; the data originally appeared in Tech. Report 36, Lund Inst. of Technology by Ahlgren Lennart, 1972.

[5a] VTT, Finland, Data; density = 430 kg·m^{-3}.

[6] Galbraith G. H., McLean, R. C.' Vapour permeability testing', Final report to the Building Research Establishment; Contract F3/2/490, Strathclyde University, June 1993; dry density 497 kg·m^{-3}, specimen thickness 25 mm.

[7] Galbraith G. H., McLean, R. C.' Vapour permeability testing', Final report to the Building Research Establishment; Contract F3/2/490, Strathclyde University, June 1993; dry density 490 kg·m^{-3}, specimen thickness 25 mm.

[8] Fraunhofer Institute of Building Physics, Holzkirchen, Germany, data; light concrete with expanded concrete; ; density between 535 and 670 kg·m^{-3}.

- **Dry density:** 430 to 800 kg·m^{-3}
- **Heat capacity:** 840 J·kg^{-1}·K^{-1}[1]
  1050 J·kg^{-1}·K^{-1}[2]
  960 J·kg^{-1}·K^{-1}[3]
- **Porosity:** ≈ 0.7 m^3.m^{-3}[2]

- **Thermal conductivity of the dry material:**

Test Method	T,Hot surface °C	T, Cold surface °C	Temperature °C	λ $W\cdot m^{-1}\cdot K^{-1}$
***	***	***	-10	0.198[2]
***	***	***	0	0.200[2]
***	***	***	20	0.202[2]
***	***	***	30	0.204[2]
***	***	***	40	0.208[2]
***	***	***	50	0.210[2]
***	***	***	60	0.212[2]
***	***	***	70	0.240[2]
***	***	***	20	0.15[4]

- **Thermal conductivity of moist material at 20 °C[2]:**

moisture content $kg\bullet kg^{-1}$	λ $W\cdot m^{-1}\cdot K^{-1}$	moisture content $kg\bullet kg^{-1}$	λ $W\cdot m^{-1}\cdot K^{-1}$
0	0.204	0.2	0.643
0.05	0.384	***	***
0.1	0.479	***	***
0.15	0.571	***	***

Reference[1] gives the following equation, at 10 °C:

$\lambda\ (W\cdot m^{-1}\cdot K^{-1}) = 0.176 + 0.000801\ w$, dry density between 598 and 626 $kg\cdot m^{-3}$

and the following equations at 20 °C:

$\lambda\ (W\cdot m^{-1}\cdot K^{-1}) = 0.177 + 0.000980\ w$, dry density between 598 and 626 $kg\cdot m^{-3}$
$\lambda\ (W\cdot m^{-1}\cdot K^{-1}) = 0.138 + 0.000904\ w$, dry density between 455 and 492 $kg\cdot m^{-3}$

where w is the moisture content ($kg\cdot m^{-3}$).

Reference [3] gives the following equation at 10 °C:
$\lambda\ (W\cdot m^{-1}\cdot K^{-1}) = 0.138 + 0.47\ u$, dry density = 560 $kg\cdot m^{-3}$
where u is the moisture content ($kg\cdot kg^{-1}$).

- **Sorption/desorption curve[4]:**

Relative humidity %	**Sorption moisture content** kg•kg^{-1}	**Desorption moisture content** kg•kg^{-1}
17.8	0.018	
17.8	0.018	
33.1	0.023	
54.8	0.024	
55.7	0.028	
75.3	0.029	
76.3	0.035	
90.3	0.046	
92.4	0.064	
95.3	0.091	
96.5	0.100	
98.0	0.165	
98.8	0.185	
17.8		0.023
17.8		0.023
32.8		0.027
33.1		0.028
54.9		0.036
55.6		0.045
75.1		0.065
76.1		0.067
91.1		0.164
92.0		0.144
97.7		0.390
98.3		0.341

- **Sorption Curve [5a]:**

Relative humidity %	**Moisture content** kg•kg^{-1}	**Relative humidity** %	**Moisture content** kg•kg^{-1}
25	0.019	70	0.042
50	0.035	90	0.065

Reference[1] gives the following equations for sorption:
$w(\mathrm{kg \cdot m^{-3}}) = 300[1 - \ln \varphi / 0.0011]^{-1/1.99}$ or
$= \varphi / (-0.1877\, \varphi^2 + 0.213\, \varphi + 0.011)$

Reference[1] gives the following equations for desorption:
$w(\mathrm{kg \cdot m^{-3}}) = 800[1 - \ln \varphi / 0.0038]^{-1/1.132}$ or
$= \varphi / (-0.156\, \varphi^2 + 0.159\, \varphi - 0.002)$

The dry density of the material is between 465 and 621 kg·m^{-3}.

- **Capillary moisture content[1]:** 109 + 0.383 ρ
- **Saturation moisture content[1]:** 972 - 0.350 ρ

where ρ is the dry density ($kg{\cdot}m^{-3}$) and the moisture content is expressed in $kg{\cdot}m^{-3}$.

Note: Reference[2] gives the saturation moisture content to be 1 $kg{\bullet}kg^{-1}$ for the specimen with a density = 700 $kg{\cdot}m^{-3}$ which agrees with the equation given above.

- **Water Vapour Permeability (from cup method):**

RH(1) %	RH(2) %	Mean RH %	Water vapour permeability at 23 °C $kg{\cdot}m^{-1}{\cdot}s^{-1}{\cdot}Pa^{-1}$ x 10^{-11}
0	60		2.29[6]
60	80		3.47[6]
60	93		4.25[6]
60	100		5.04[6]
0	60		2.16[7]
60	80		2.50[7]
60	93		2.87[7]
60	100		3.35[7]
3	50		2.07[8]
3	50		2.41[8]
3	50		3.10[8]
3	50		3.38[8]
3	50		3.72[8]
		20	1.8[5a]
		50	2.2[5a]
		75	4.2[5a]
		95	6.3[5a]

Reference[1] gives the following equation for the vapour resistance factor, μ:

$\mu = 1/[1.16 \times 10^{-1} + 6.28 \times 10^{-3} \exp(4.19\varphi)]$ with relative humidity φ expressed as a fraction, with the density of the material between 458 and 770 $kg{\cdot}m^{-3}$.

- **Moisture diffusivity**:

Moisture content ($kg{\bullet}kg^{-1}$)	Moisture diffusivity ($m^2{\cdot}s^{-1}$)
0.02	4.31E-09[2]
0.12	1.47E-09[2]
0.22	6.67E-09[2]
0.32	4.17E-08[2]

Moisture content ($kg \cdot kg^{-1}$)	**Moisture diffusivity ($m^2 \cdot s^{-1}$)**
0.42	1.43E-07[2]
0.52	6.00E-08[2]
0.62	2.00E-08[2]
0.72	2.00E-08[2]
0.82	4.79E-08[2]
0.92	1.97E-07[2]
0.1	2E-09[5a]
0.2	2E-09[5a]
0.3	1.7E-09[5a]
0.4	1.5E-09[5a]
0.5	1.2E-09[5a]

Reference[1] gives the following equation for moisture diffusivity, D_W:

D_W ($m^2 \cdot s^{-1}$) = $9.2 \times 10^{-11} \exp(0.0215\ w)$

where w is the moisture content expressed in $kg \cdot m^{-3}$, the density of the material = 511 $kg \cdot m^{-3}$.

- **Suction curve[2] at 20 °C :**

P, Pa	1×10^8	1.4×10^7	5.0×10^6	1.6×10^5	4.5×10^4	2.0×10^4
u, $kg \cdot kg^{-1}$	0.05	0.25	0.40	0.0077	0.50	0.60

P, Pa	1.0×10^4	4.8×10^3	1.5×10^3	6.5×10^2
u, $kg \cdot kg^{-1}$	0.70	0.80	0.90	0.95

- **Thermal moisture diffusion coefficient at 20 °C as a function of moisture content[2]:**

u, ($kg \cdot kg^{-1}$)	0.02	0.12	0.22	0.32	0.42
D_T, ($m^2 \cdot s^{-1} \cdot K^{-1}$) x 10^{-12}	9.7	34.4	80.0	480	14.3

u, ($kg \cdot kg^{-1}$)	0.52	0.62	0.72	0.82	0.92
D_T, ($m^2 \cdot s^{-1} \cdot K^{-1}$) x 10^{-12}	1.2	0.1	0.02	0.01	0.01

Water Absorption Coefficient[8]: 0.066 to 0.128 $kg \cdot m^{-2} \cdot s^{-1/2}$

2.4 Brick

- SOURCES

[1] Catalogue of Material properties(upgraded version), Report Annex XIV, Page 2.7

[2] Laboratoire de Thermique des Materiaux et des Batiments, INSA, Toulouse, France, data, Brique, density of specimen 1800 kg·m^{-3}.

[2a] VTT Finland data, density of specimen 1980 kg·m^{-3}; red brick.

[3] Institute for Research in Construction, NRC, Canada, data; density of the sample being 1676 kg·m^{-3}; thickness of test specimen 11 mm; clay brick.

[4] Institute for Research in Construction, NRC, Canada, data; density of the samples being 1728 kg·m^{-3}; thickness of test specimen 11 mm; sand-lime brick.

[5] Kurt Kielsgaard Hansen, Sorption Isotherms, A Catalogue, The Technical University of Denmark, Technical Report 162/86; the data corresponds to a brick sample with a density = 1890 kg·m^{-3}; the data originally appeared in Tech. Report 36, Lund Inst. of Technology by Ahlgren Lennart, 1972. The document lists data on three other brick samples as well.

[6] Fraunhofer Institute of Building Physics, Holzkirchen, Germany, data.

[7] Galbraith G. H., McLean, R. C.' Vapour permeability testing', Final report to the Building Research Establishment; Contract F3/2/490, Strathclyde University, June 1993; density 1676 kg·m^{-3}, specimen thickness 25 mm.

- **Dry density:** 1100 to 2150 kg·m^{-3}
- **Heat capacity:** 840 J·kg^{-1}·K^{-1}[1]
  920 J·kg^{-1}·K^{-1}[2]
- **Porosity**: ≈ 0.11 m^3·m^{-3}[2]
  ≈ 0.25 m^3·m^{-3}[2a]

- **Thermal conductivity of the dry material:**

Test Method	T,Hot surface °C	T, Cold surface °C	Temperature °C	λ W·m^{-1}·K^{-1}
***	9.22	5.48		0.397[3]
***	31.90	27.87		0.435[3]
***	9.34	5.32		0.400[4]
***	31.57	27.39		0.419[4]
***	***	***	5	1.01[2]
***	***	***	10	1.01[2]
***	***	***	20	1.00[2]

Test Method	T,Hot surface °C	T, Cold surface °C	Temperature °C	λ W·m^{-1}·K^{-1}
***	***	***	30	0.99[2]
***	***	***	40	0.98[2]
***	***	***	50	0.96[2]

- **Thermal conductivity of moist material at 20 °C[2]:**

moisture content kg•kg^{-1}	λ W·m^{-1}·K^{-1}	moisture content kg•kg^{-1}	λ W·m^{-1}·K^{-1}
0	1.0	0.07	1.55
0.02	1.21	0.12	2.0
0.04	1.42	***	***

- **Thermal conductivity of moist material at 30 °C:**

moisture content kg•kg^{-1}	λ W·m^{-1}·K^{-1}	moisture content kg•kg^{-1}	λ W·m^{-1}·K^{-1}
0.16	0.782[3]	0.11	0.617[4]

- **Sorption/desorption curve[5]:**

Relative humidity %	Sorption moisture content kg•kg^{-1}	Desorption moisture content kg•kg^{-1}
25.0	0.0023	
44.9	0.0028	
45.3	0.0026	
65.1	0.0027	
65.4	0.0032	
85.2	0.0030	
85.6	0.0036	
95.2	0.0041	
96.1	0.0046	
98.3	0.0055	
98.4	0.0059	
19.9		0.0022
20.4		0.0020
40.2		0.0031
40.7		0.0028
60.4		0.0034
60.7		0.0038

Relative humidity %	Sorption moisture content $kg \cdot kg^{-1}$	Desorption moisture content $kg \cdot kg^{-1}$
80.3		0.0044
80.7		0.0049
95.2		0.0071
95.4		0.0060

- **Sorption curve[2]:**

Relative humidity %	Sorption moisture content $kg \cdot kg^{-1}$
5	0.00015
10	0.0003
20	0.0006
30	0.0009
40	0.0012
50	0.0015
60	0.00244
70	0.00338
80	0.00432
90	0.0062
95	0.0076
100	0.009

- **Sorption curve[6]:**

Relative humidity %	Density $kg \cdot m^{-3}$	Sorption moisture content $kg \cdot kg^{-1}$
75	1400	0.0014
85	1400	0.0019
75	1600	0.0009 to 0.001
85	1600	0.001 to 0.0015
75	1900	0.00057
85	1900	0.00063 to 0.0019
75	2100	0.00067
85	2100	0.00067
75	2200	0.00068
85	2200	0.00086 to 0.00091
75	2300	0.00087
85	2300	0.00087

- **Sorption Curve [2a]:**

Relative humidity %	Moisture content $kg \bullet kg^{-1}$	Relative humidity %	Moisture content $kg \bullet kg^{-1}$
25	0.0003	70	0.0006
50	0.0005	90	0.0014

Reference[1] gives the following equations for sorption:

$$w(kg{\cdot}m^{-3}) = 200[1 - \ln \varphi / 0.000146]^{-1/1.59} \text{ or}$$

$$= \varphi / (-8.234\, \varphi^2 + 9.649\, \varphi - 1.484)$$

- **Capillary moisture content[1]:** $730.3 - 0.287\,\rho$ $(kg{\cdot}m^{-3})$
- **Capillary moisture content[3]:** 270 $kg{\cdot}m^{-3}$
- **Capillary moisture content[4]:** 190 $kg{\cdot}m^{-3}$
- **Saturation moisture content[1]:** $1033 - 0.4036\,\rho$ $(kg{\cdot}m^{-3})$ with the density, ρ, varying between 1505 and 2047 $kg{\cdot}m^{-3}$.
- **Water Vapour Permeability (from cup method):**

RH(1) %	RH(2) %	Mean RH %	Water vapour permeability at 23 °C $kg{\cdot}m^{-1}{\cdot}s^{-1}{\cdot}Pa^{-1} \times 10^{-11}$
0	60		1.13[7]
60	80		1.21[7]
60	93		1.45[7]
60	100		1.48[7]
		25	2.6[2]
		50	2.6[2]
		75	2.6[2]
		95	2.6[2]
		25	1.1[2a]
		50	1.6[2a]
		75	2.3[2a]
		95	3.2[2a]
3	50		1.24[6], ρ =1600 $kg{\cdot}m^{-3}$
3	50		0.1[6], ρ =1830 $kg{\cdot}m^{-3}$
3	50		0.53[6], ρ =1900 $kg{\cdot}m^{-3}$
3	50		0.33[6], ρ =2200 $kg{\cdot}m^{-3}$

Reference[1] gives the following equation for the vapour resistance factor, μ

$\mu = 1/[5.36 \times 10^{-2} + 4.67 \times 10^{-3} \exp(2.79\varphi)]$ with relative humidity φ expressed as a fraction.

- **Moisture diffusivity at 20 °C[2]:**

Moisture content ($kg\cdot kg^{-1}$)	Moisture diffusivity ($m^2\cdot s^{-1}$)	Moisture content ($kg\cdot kg^{-1}$)	Moisture diffusivity ($m^2\cdot s^{-1}$)
0.0027	2.0E-9	0.080	2.19E-8
0.0054	2.0E-9	0.100	4.57E-8
0.020	2.51E-9	0.110	6.76E-8
0.040	5.89E-9	0.120	1.17E-7
0.060	1.21E-8		

- **Moisture diffusivity at 20 °C[2a]:**

Moisture content ($kg\cdot kg^{-1}$)	Moisture diffusivity ($m^2\cdot s^{-1}$)
0.05	3.5E-10
0.1	2.3E-10

- **Moisture diffusivity at 20 °C[3]:**

Moisture content ($kg\cdot kg^{-1}$)	Moisture diffusivity ($m^2\cdot s^{-1}$)
0.0011	1.49E-08
0.0057	5.3E-08
0.0103	7.23E-08
0.0157	8.52E-08
0.0204	9.24E-08
0.0314	1.08E-07
0.0413	1.28E-07
0.0509	1.55E-07
0.0607	2.07E-07
0.0703	3.05E-07
0.0803	4.49E-07
0.0868	5.48E-07
0.0900	7.18E-07
0.0928	2.07E-06

- **Moisture diffusivity at 20 °C[4]:**

Moisture content ($kg\cdot kg^{-1}$)	Moisture diffusivity ($m^2\cdot s^{-1}$)
0.0011	8.07E-08
0.0057	2.88E-07
0.0103	3.92E-07

Moisture content ($kg \cdot kg^{-1}$)	**Moisture diffusivity ($m^2 \cdot s^{-1}$)**
0.0157	4.62E-07
0.0204	5.02E-07
0.0314	5.85E-07
0.0413	6.94E-07
0.0509	8.41E-07
0.0607	1.12E-06
0.0703	1.66E-06
0.0803	2.44E-06
0.0868	2.97E-06
0.0900	3.90E-06
0.0928	1.12E-05

Reference[1] gives the following equations for moisture diffusivity, D_W:

D_W ($m^2 \cdot s^{-1}$) = $2.1 \times 10^{-9} \exp(0.0316\ w)$

where w is the moisture content expressed in $kg \cdot m^{-3}$, the density of the material being 1529 $kg \cdot m^{-3}$.

D_W ($m^2 \cdot s^{-1}$) = $1.9 \times 10^{-8} \exp(0.022\ w)$

where w is the moisture content expressed in $kg \cdot m^{-3}$, the density of the material being 1619 $kg \cdot m^{-3}$.

D_W ($m^2 \cdot s^{-1}$) = $7.4 \times 10^{-9} \exp(0.0316\ w)$

where w is the moisture content expressed in $kg \cdot m^{-3}$, the density of the material being 1918 $kg \cdot m^{-3}$.

- **Suction curve[2] at 20 °C :**

P, Pa	5.5×10^8	0.9×10^8	0.5×10^8	$1. \times 10^7$	1.0×10^6	4.07×10^5
u, $kg \cdot kg^{-1}$	0	0.0018	0.0036	0.006	0.012	0.036

P, Pa	8.4×10^4	3.61×10^4	6.7×10^3	1.0×10^3
u, $kg \cdot kg^{-1}$	0.072	0.096	0.114	0.12

- **Thermal moisture diffusion coefficient at 20 °C as a function of moisture content[2]:**

u, ($kg \cdot kg^{-1}$)	**0.0027**	**0.0054**	**0.020**	**0.040**	**0.060**	**0.080**	**0.10**	**0.11**	**0.12**
D_T, ($m^2 \cdot s^{-1} \cdot K^{-1}$) x 10^{-12}	4.66	7.22	11.5	23.4	32.6	34.6	31.6	26.9	19.9

- **Water Absorption Coefficient:** 0.3 $kg \cdot m^{-2} \cdot s^{-½}$; ρ =1100 $kg \cdot m^{-3}$[6]
  0.5 $kg \cdot m^{-2} \cdot s^{-½}$; ρ =1560 $kg \cdot m^{-3}$[6]
  0.4 $kg \cdot m^{-2} \cdot s^{-½}$; ρ =1730 $kg \cdot m^{-3}$[6]
  0.4 $kg \cdot m^{-2} \cdot s^{-½}$; ρ =1750 $kg \cdot m^{-3}$[6]
  0.05 $kg \cdot m^{-2} \cdot s^{-½}$; ρ =2150 $kg \cdot m^{-3}$[6]
  0.112 $kg \cdot m^{-2} \cdot s^{-½}$[3]
  0.121 $kg \cdot m^{-2} \cdot s^{-½}$[4]

Reference[1] gives the following equation for clay bricks:
Water absorption coefficient = $0.653 - 0.0003\ \rho$, with the density, ρ, between 1505 and 2000 $kg \cdot m^{-3}$.

2.5 Cement Mortar

- **SOURCES**

[1] Catalogue of Material properties(upgraded version), Report Annex XIV, Page 2.6

[2] Laboratoire de Thermique des Materiaux et des Batiments, INSA, Toulouse, France, data, Beton Cellulaire, density of specimen 2050 $\text{kg}\cdot\text{m}^{-3}$.

[3] Institute for Research in Construction, NRC, Canada, data; density of the samples being 2210 $\text{kg}\cdot\text{m}^{-3}$.

[4] Laboratory of Building Physics, KULeuven, Belgium Data, density of material being 1786 $\text{kg}\cdot\text{m}^{-3}$

[5] Kurt Kielsgaard Hansen, Sorption Isotherms, A Catalogue, The Technical University of Denmark, Technical Report 162/86; the data corresponds to a cement mortar sample with a density = 2000 $\text{kg}\cdot\text{m}^{-3}$ and the following specification: 1:4, w/c = 0.7, wn/c = 0.2; the data originally appeared in Tech. Report 36, Lund Inst. of Technology by Ahlgren Lennart, 1972.

[6] Kurt Kielsgaard Hansen, Sorption Isotherms, A Catalogue, The Technical University of Denmark, Technical Report 162/86; the data corresponds to a cement mortar sample with a density = 2000 $\text{kg}\cdot\text{m}^{-3}$ and the following specification: 1:4, w/c = 0.8, open porosity = 22 %; the data originally appeared in Tech. Report 36, Lund Inst. of Technology by Ahlgren Lennart, 1972.

- **Dry density:** 1050 to 2200 $\text{kg}\cdot\text{m}^{-3}$

- **Heat capacity:** 840 $\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$[1]
  932 $\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$[2]
  980 $\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$[3]

- **Porosity**: ≈ 0.327 $\text{m}^3\cdot\text{m}^{-3}$[4]

- **Thermal conductivity of the dry material:**

Test Method	T,Hot surface °C	T, Cold surface °C	Temperature °C	λ $\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$
ASTM C518	***	***	3	1.71[3]
ASTM C518	***	***	23	1.71[3]
***	***	***	5	2.04[2]
***	***	***	10	2.035[2]
***	***	***	20	1.99[2]
***	***	***	30	1.965[2]
***	***	***	40	1.92[2]

Reference[1] gives the following equation for the dry material at 20 °C, with the density, ρ, between 1055 and 1822 $\text{kg}\cdot\text{m}^{-3}$:

$$\lambda = 0.088 \exp(0.00125\,\rho)$$

- **Thermal conductivity of moist material at 20 °C[2]:**

moisture content $kg\cdot kg^{-1}$	**λ** $W\cdot m^{-1}\cdot K^{-1}$	**moisture content** $kg\cdot kg^{-1}$	**λ** $W\cdot m^{-1}\cdot K^{-1}$
0	1.722	0.04	2.232
0.01	1.942	0.05	2.282
0.02	2.092	0.06	2.322
0.03	2.172	0.07	2.372

Reference[1] gives the following equations, at 20 °C:

$\lambda\ (W\cdot m^{-1}\cdot K^{-1}) = 0.346 + 0.0012\,w$, dry density being 1072 $kg\cdot m^{-3}$
$\lambda\ (W\cdot m^{-1}\cdot K^{-1}) = 0.526 + 0.0031\,w$, dry density being 1512 $kg\cdot m^{-3}$
$\lambda\ (W\cdot m^{-1}K^{-1}) = 0.854 + 0.0045\,w$, dry density being 1800 $kg\cdot m^{-3}$
where w is the moisture content ($kg\cdot m^{-3}$).

- **Sorption/desorption curve[5]:**

Relative humidity %	**Sorption moisture content** $kg\cdot kg^{-1}$	**Desorption moisture content** $kg\cdot kg^{-1}$
25.1	0.0117	
25.4	0.0126	
44.5	0.0156	
45.1	0.0166	
64.8	0.0268	
65.2	0.0226	
84.7	0.0328	
85.4	0.0330	
95.2	0.0461	
95.6	0.0467	
97.6	0.0538	
97.7	0.0548	
19.1		0.0121
19.8		0.0136
39.3		0.0248
39.7		0.0211
59.2		0.0308
59.7		0.0336
79.2		0.0457
79.6		0.0400
94.2		0.0549
94.6		0.0527

- **Sorption/desorption curve[6]:**

Relative humidity %	Sorption moisture content $kg \cdot kg^{-1}$	Desorption moisture content $kg \cdot kg^{-1}$
24.7	0.0079	
25.0	0.0097	
44.8	0.0132	
45.3	0.0112	
65.1	0.0202	
65.6	0.0191	
84.6	0.0318	
85.0	0.0292	
94.9	0.0501	
95.1	0.0483	
97.3	0.0595	
98.1	0.0585	
19.5		0.0092
20.1		0.0078
39.9		0.0204
40.4		0.0179
60.0		0.0301
60.4		0.0275
80.1		0.0464
80.4		0.0406
94.9		0.0584
95.4		0.0541

- **Sorption/desorption curve[4]:**

Relative humidity %	Sorption moisture content $kg{\cdot}kg^{-1}$	Desorption moisture content $kg{\cdot}kg^{-1}$
34.6	0.020	
54.4	0.021	
75.4	0.036	
85.7	0.043	
98.3	0.075	
34.6		0.025
54.4		0.027
75.4		0.044
85.1		0.056
98.3		0.108

Reference[1] gives the following equations for sorption:

$$w(kg{\cdot}m^{-3}) = 283[1 - \ln \varphi / 0.029]^{-1/1.39} \text{ or}$$
$$= \varphi / (-0.052\,\varphi^2 + 0.052\,\varphi + 0.005)$$

Reference[1] gives the following equations for desorption:

$$w(kg{\cdot}m^{-3}) = 300[1 - \ln \varphi / 0.061]^{-1/1.77} \text{ or}$$
$$= \varphi / (-0.022\,\varphi^2 + 0.025\,\varphi + 0.0001)$$

The dry density of the material is 1940 $kg{\cdot}m^{-3}$.

- **Capillary moisture content[1]:** 283 $kg{\cdot}m^{-3}$

- **Water Vapour Permeability (from cup method):**

RH(1) %	RH(2) %	Mean RH %	Water vapour permeability at 23 °C $kg{\cdot}m^{-1}{\cdot}s^{-1}{\cdot}Pa^{-1} \times 10^{-12}$
52	86		6.35[4]
86	97		10.31[4]
0	10		8.97[2]
10	20		4.95[2]
20	30		2.77[2]
30	40		2.73[2]
40	50		3.42[2]
50	60		9.52[2]
60	70		13.57[2]
70	80		16.67[2]
80	90		54.67[2]
90	100		79.5[2]

Reference[1] gives the following equation for the vapour resistance factor, μ:

$\mu = 1/[7.69 \times 10^{-2} + 2.43 \times 10^{-3} \exp(3.61\varphi)]$ with relative humidity φ expressed as a fraction.

- **Moisture diffusivity**:

Moisture content ($kg \cdot kg^{-1}$)	Moisture diffusivity ($m^2 \cdot s^{-1}$)
0.056	1.0E-08[4]
0.076	1.7E-08[4]
0.084	3.2E-08[4]
0.090	6.8E-08[4]
0.01	2.0E-09[2]
0.02	4.0E-09[2]
0.03	5.6E-09[2]
0.04	8.9E-09[2]
0.05	1.4E-08[2]
0.06	2.0E-08[2]

Reference[1] gives the following equations for moisture diffusivity, D_W:

$D_W\ (m^2 \cdot s^{-1}) = 2.0 \times 10^{-9} \exp(0.0220\ w)$

where w is the moisture content expressed in $kg \cdot m^{-3}$, the density of the material being 1072 $kg \cdot m^{-3}$.

$D_W\ (m^2 \cdot s^{-1}) = 2.7 \times 10^{-9} \exp(0.0204\ w)$

where w is the moisture content expressed in $kg \cdot m^{-3}$, the density of the material being 1500 $kg \cdot m^{-3}$.

$D_W\ (m^2 \cdot s^{-1}) = 1.4 \times 10^{-9} \exp(0.0270\ w)$

where w is the moisture content expressed in $kg \cdot m^{-3}$, the density of the material being 1807 $kg \cdot m^{-3}$.

- **Suction curve[2] at 20 °C :**

P, Pa	3.2×10^8	2.2×10^8	1.7×10^8	1.3×10^8	9.6×10^7	7.1×10^7
u, $kg \cdot kg^{-1}$	0.0026	0.0053	0.0079	0.0105	0.0137	0.0195

P, Pa	4.9×10^7	3.1×10^7	1.5×10^7	4.0×10^6
u, $kg \cdot kg^{-1}$	0.0252	0.0310	0.0452	0.0600

- **Suction curve[4] at 20 °C,** pressure relative to atmospheric pressure :

P, Pa	5.934×10^5	6.966×10^5	7.532×10^5	11.135×10^5	12.701×10^5	14.01×10^5
u, $kg \cdot kg^{-1}$	0.087	0.082	0.098	0.093	0.089	0.094

P, Pa	0.108×10^5	0.196×10^5	0.249×10^5	0.425×10^5	0.853×10^5
u, $kg \cdot kg^{-1}$	0.158	0.155	0.158	0.146	0.130

P, Pa	1.127×10^5	1.832×10^5	3.247×10^5	4.000×10^5	5.852×10^5
u, $kg \cdot kg^{-1}$	0.119	0.112	0.115	0.108	0.096

- **Thermal moisture diffusion coefficient at 20 °C as a function of moisture content[2]**

u, $(kg \cdot kg^{-1})$	0.01	0.02	0.03	0.04	0.05	0.06	0.07
D_T, $(m^2 \cdot s^{-1} \cdot K^{-1}) \times 10^{-12}$	0.63	5.0	6.3	6.3	6.3	3.5	0.40

- **Water Absorption Coefficient[1]: 0.042 to 0.8 $kg \cdot m^{-2} \cdot s^{-1/2}$**

2.6 Gypsum Board

- **SOURCES**

[1] Catalogue of Material properties, Report Annex XIV, Volume 3, Page 2.34

[2] NRC Canada, data, pressure-volume measurements; density of the sample was 650 kg·m^{-3}.

[2a] NRC Canada, data, free water intake measurements; density of the sample was 620 kg·m^{-3}.

[3] NRC Canada data; density of specimen 669 kg·m^{-3} and thickness 12.6 mm.

[4] Laboratory of Building Physics, KU-Leuven, Belgium, data; density of specimen 747 kg·m^{-3} and thickness 9.6 mm.

[5] Laboratory of Building Physics, KU-Leuven, Belgium, data; density of specimen 746 kg·m^{-3} and thickness 9.6 mm.

[6] Catalogue of Material properties, Report Annex XIV, Volume 3, Page 2.34 (corrected version, from KU-Leuven, Belgium).

[7] NIST, USA data, Richards et al., ASHRAE Transactions 1992, V.98, Pt. 2

[8] NRC Canada, data.

[9] Dipartimento di Energetica, Universita di Ancona, Italy, data, density of specimen 764 kg.m^{-3} and thickness 12.3 mm.

[10] Burch et al., ASHRAE Transactions 1992, V. 98, Pt. 2

[11] McLean et al., Building Research and Practice, No. 2, 1990, p 82-91.

[12] Laboratory of Building Physics, KU-Leuven, Belgium, data, density of specimen 746 kg·m^{-3} and thickness 9.6 mm

[13] Data from CMHC Canada report on "Air permeance of building materials"; specimens were 1 m x 1 m and 12.7 mm thick.

- **Dry density:** 700 ± 80 kg·m^{-3}
- **Heat capacity[1]:** 870 J·kg^{-1}·K^{-1}
- **Porosity[2]:** ≈ 0.7 m^3·m^{-3}

- **Thermal conductivity of the dry material:**

Test Method	T,Hot surface °C	T, Cold surface °C	λ W·m⁻¹·K⁻¹
ASTM C518	35.0	13.0	0.164[3]
***	12.3	7.7	0.22[4]
***	22.7	16.9	0.22[4]
***	32.2	27.0	0.22[4]
***	12.2	7.0	0.195[5]
***	22.0	16.9	0.195[5]
***	32.15	27.75	0.199[5]

- **Thermal conductivity of moist material:**

Specimen Temperature °C	Moisture content kg•kg⁻¹	λ W·m⁻¹·K⁻¹
9.8	0.023	0.24[4]
9.8	0.026	0.24[4]
19.6	0.023	0.24[4]
19.6	0.026	0.24[4]
29.6	0.023	0.24[4]
29.6	0.026	0.245[4]
10.6	0.0185	0.234[5]
10.6	0.024	0.245[5]
19.6	0.0185	0.239[5]
19.6	0.024	0.245[5]
29.6	0.0185	0.239[5]
29.6	0.024	0.245[5]

- **Sorption/desorption curve[6]:**

Relative humidity %	Sorption moisture content kg·m⁻³	Desorption moisture content kg·m⁻³
10	23.3	84.7
20	25.1	88.6
30	26.7	91.8
40	28.2	95.0
50	30.0	98.3
60	31.9	102.0
70	34.4	106.5
80	37.9	112.5
90	44.3	122.1
95	51.4	130.6
98	62.3	139.4

- **Sorption/desorption curve[7]:**

Relative humidity %	Sorption moisture content kg•kg^{-1}(kg·m^{-3})	Desorption moisture content kg•kg^{-1}(kg·m^{-3})
11.3	0.001(0.67)	0.001(0.67)
32.8	0.003(2.01)	0.003(2.01)
43.2	0.004(2.68)	0.005(3.35)
57.6	0.005(3.35)	0.007(4.69)
78.6	0.009(6.03)	0.010(6.70)
84.3	0.010(6.70)	0.012(8.04)
93.6	0.019(12.73)	0.019(12.73)
97.3	0.027(18.09)	0.028(18.76)

- **Capillary moisture content:** ≈ 400 kg·m^{-3}[2a]

- **Water Vapour Permeability (from cup method):**

RH(1) %	RH(2) %	Water vapour permeability at various temperatures, kg·m^{-1}·s^{-1}·Pa^{-1} x 10^{-11}				
		10 °C	15 °C	20 °C	23 °C	25 °C
0	60	2.00[11]				
60	100	2.39[11]				
65	94	2.65[11]				
80	100	3.04[11]				
0	60		2.18[11]			
60	100		2.37[11]			
65	94		2.42[11]			
80	100		2.69[11]			
0	60			2.13[11]		
60	90			2.28[11]		
60	100			2.66[11]		
80	100			3.04[11]		
0	28.7				3.3[8]	
0	50.9				3.0[8]	
22.7	50.8				2.5[8]	
43.2	61.5				2.5[8]	
50.9	69.1				3.8[8]	
61.5	81.2				4.2[8]	
61.4	100				4.0[8]	
80.4	100				5.2[8]	
92.4	100				6.5[8]	
3	40				2.2[9]	
3	65				2.2[9]	
50	97				3.7[9]	
0	60					2.10[11]

RH(1) %	**RH(2) %**	**Water vapour permeability at various temperatures, kg·m^{-1}·s^{-1}·Pa^{-1} x 10^{-11}**				
		10 °C	**15 °C**	**20 °C**	**23 °C**	**25 °C**
60	90					2.26[11]
60	100					2.44[11]
80	100					2.82[11]

A NIST, USA publication[10] gives the following equation for the permeance of a 13 mm thick plain gypsum board as a function of relative humidity,ϕ (expressed as a fraction) at either 7 or 25 °C:

$$\text{permeance } (\text{kg·m}^{-2}\text{·s}^{-1}\text{·Pa}^{-1}) = \text{Exp}(-19.479-0.0789\phi).$$

McLean et al.[11] reported the following equations for the permeability (kg·m^{-1}·s^{-1}·Pa^{-1}), as a function of RH(%), at 20 °C:

Thin plasterboard (9 mm): $(1.68+ 0.0124RH)\text{x } 10^{-11}$
Thick plasterboard (12 mm): $(1.78 + 0.018RH) \text{ x } 10^{-11}$

- **Moisture diffusivity**[2a]:

Moisture content (kg·m^{-3})	**Moisture diffusivity (m^2·s^{-1})**
2	8.6E-08
4	1.7E-07
7	2.6E-07
10	3.5E-07
12	4.2E-07
16	5.1E-07
18	5.7E-07
22	3.7E-07
24	1.1E-07
28	5.7E-08
39	4.0E-08
60	3.4E-08
94	3.1E-08
145	3.6E-08
186	5.8E-08
209	9.9E-08
226	1.4E-07
239	1.9E-07
249	2.6E-07
256	3.5E-07
261	4.3E-07
278	4.7E-07
310	4.8E-07
351	4.2E-07
394	3.7E-07

- **Air permeability:**

Pressure difference Pa	Permeability[12] $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1} x10^{-10}$
50	9.23
100	8.54
150	8.16
200	7.9

Pressure difference Pa	Permeability[13] $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1} x10^{-9}$
25	4.0
50	4.0
75	4.0
100	4.0

2.7 Pine

- SOURCES

[1] Catalogue of Material properties(upgraded version), Report Annex XIV, Page 2.16

[2] Institute for Research in Construction, NRC Canada, data on eastern white pine.

[2a] Institute for Research in Construction, NRC Canada, data on eastern white pine; density of the test specimen 355.5 kg·m^{-3}.

[2b] Institute for Research in Construction, NRC Canada, data; density of the test specimen 424 kg·m^{-3}.

[3] Lars Wadso. Studies of Water Vapor Transport and Sorption in Wood. Lund University, Report TVBM-1013, 1993, page 5.

[4] Kurt Kielsgaard Hansen, Sorption Isotherms, A Catalogue, The Technical University of Denmark, Technical Report 162/86; the data corresponds to a pine sample with a density = 510 kg·m^{-3}; the data originally appeared in Tech. Report 36, Lund Inst. of Technology by Ahlgren Lennart, 1972.

[5] Richards, R. F., Burch, D. M. and Thomas, W. C. Water Vapor Sorption Measurements of Common Building Materials. ASHRAE Transactions, 1992, V.98, Pt. 2; the data are on southern pine with density 565 kg·m^{-3}.

[6] Richards, R. F., Burch, D. M. and Thomas, W. C. Water Vapor Sorption Measurements of Common Building Materials. ASHRAE Transactions, 1992, V.98, Pt. 2; the data are on sugar pine with density 365 kg·m^{-3}.

[6a] VTT Finland data; density of the sample 340 kg· m^{-3}.

[7] Calculated using the equation reported by Burch, D. M., Thomas, W. C. and Fanney, A. H.; ASHRAE Transactions 1992, V.98, Pt.2.

- **Dry density:** 400 kg·m^{-3}[1]
  370 ± 10 kg·m^{-3}[2]
  450 kg·m^{-3}[3]
  365 kg·m^{-3}[6]
  565 kg·m^{-3}[5]
- **Heat capacity:** 1880 J·kg^{-1}·K^{-1}[1]
- **Porosity**: ≈ 0.8 m^3·m^{-3}

- **Thermal conductivity of the dry material:**

Test Method	T,Hot surface °C	T, Cold surface °C	Mean temperature °C	Orientation	λ $W \cdot m^{-1} \cdot K^{-1}$
***				longitudinal	0.25[3]
***				transversal	0.1[3]
***			20	***	0.11[1]
ASTM C518	34.78	13.85		transversal	0.0944[2a]
"	18.85	-12.83		"	0.0918[2a]
"	32.07	21.73		longitudinal	0.229[2a]
"	34.02	14.60		transversal	0.0946[2b]
"	1.91	-16.9		"	0.0906[2b]

- **Sorption/desorption curve[4]:**

Relative humidity %	Sorption moisture content $kg \cdot kg^{-1}$	Desorption moisture content $kg \cdot kg^{-1}$
20.5	0.057	
21.0	0.062	
43.3	0.089	
43.5	0.094	
65.6	0.120	
66.0	0.125	
85.8	0.177	
86.2	0.182	
95.4	0.241	
95.9	0.244	
98.2	0.292	
98.5	0.296	
20.5		0.075
45.6		0.116
65.8		0.149
80.3		0.196
90.4		0.236
94.8		0.271

- **Sorption/desorption curve[5]:**

Relative humidity %	Sorption moisture content $kg \cdot kg^{-1}$	Desorption moisture content $kg \cdot kg^{-1}$
11.3	0.019	0.023
32.8	0.051	0.062
43.2	0.067	0.081
57.6	0.090	0.111
78.6	0.131	0.160
84.3	0.153	0.185
93.6	0.204	0.236
97.3	0.257	0.271

- **Sorption/desorption curve[6]:**

Relative humidity %	Sorption moisture content $kg \cdot kg^{-1}$	Desorption moisture content $kg \cdot kg^{-1}$
11.3	0.016	0.020
32.8	0.046	0.056
43.2	0.060	0.073
57.6	0.084	0.101
78.6	0.132	0.156
84.3	0.158	0.181
93.6	0.205	0.234
97.3	0.244	0.247

Reference[1] gives the following equations for sorption:

$$w(kg \cdot m^{-3}) = 100[1 - \ln \varphi / 0.642]^{-1/0.64} \text{ or } = \varphi / (-0.027 \varphi^2 + 0.027 \varphi + 0.0089)$$

and the following equations for desorption:

$$w(kg \cdot m^{-3}) = 120[1 - \ln \varphi / 0.248]^{-1/1.22} \text{ or } = \varphi / (-0.021 \varphi^2 + 0.026 \varphi + 0.0041)$$

- **Water Vapour Permeability (from cup method):**

RH(1) %	RH(2) %	Mean RH %	Orientation	Water vapour permeability $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1} \times 10^{-13}$
0	50.2		transversal	2.6[2]
		25	longitudinal	290[6a]
		50	"	400[6a]
		75	"	740[6a]
		95	"	1190[6a]
		53	***	32.9[1]
		86	***	143[1]

RH(1) %	RH(2) %	Mean RH %	Orientation	Water vapour permeability $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1}$ x 10^{-13}
		20	***	3.5[7]
		40	***	5.1[7]
		60	***	11[7]
		80	***	31[7]
		90	***	63[7]
		95	***	91[7]

- **Moisture diffusivity at 20 °C, longitudinal[2]:**

Specimen 1

Moisture content ($kg \cdot kg^{-1}$)	Moisture diffusivity ($m^2 \cdot s^{-1}$)
0.218	9.4E-10
0.300	8.5E-10
0.409	7.5E-10
0.490	6.9E-10
0.600	6.3E-10
0.708	6.0E-10
0.817	5.8E-10
0.899	5.9E-10
1.001	6.4E-10
1.117	7.5E-10
1.253	1.1E-09
1.335	1.5E-09

Specimen 2

Moisture content ($kg \cdot kg^{-1}$)	Moisture diffusivity ($m^2 \cdot s^{-1}$)
0.219	6.4E-10
0.239	5.0E-10
0.283	3.8E-10
0.303	3.6E-10
0.407	2.9E-10
0.498	2.6E-10
0.611	2.4E-10
0.690	2.3E-10
0.811	2.2E-10
0.914	2.1E-10
1.029	2.0E-10
1.111	2.0E-10

Moisture content ($kg \cdot kg^{-1}$)	**Moisture diffusivity ($m^2 \cdot s^{-1}$)**
1.199	1.9E-10
1.292	1.8E-10
1.341	1.8E-10
1.496	1.7E-10

Note: Moisture intake measurements done at NRC, in the transverse direction, gave an estimate of $D_W \approx 2.3$ E-11 $m^2 \cdot s^{-1}$; the process was very slow.

- **Water Absorption Coefficient:** 0.0040 $kg \cdot m^{-2} \cdot s^{-1/2}$; transversal[1]
  0.0163 $kg \cdot m^{-2} \cdot s^{-1/2}$; longitudinal[1]

2.8 Spruce

- **SOURCES**

[1] Institute for Research in Construction, NRC Canada, data .

[2] Catalogue of Material properties(upgraded version), Report Annex XIV, Page 2.16

[3] Lars Wadso. Studies of Water Vapor Transport and Sorption in Wood.Lund University Report TVBM-1013, 1993, page 5.

[4] Kurt Kielsgaard Hansen, Sorption Isotherms, A Catalogue, The Technical University of Denmark, Technical Report 162/86; the data corresponds to a spruce sample with a density = 420 kg·m^{-3}; the data originally appeared in Tech. Report 36, Lund Inst. of Technology by Ahlgren Lennart, 1972.

[5] Tveit, A. Measurements of Moisture Sorption and Moisture Permeability of Porous Materials. Norwegian Building Research Institute Rapport 45, Oslo 1966, page 20. (estimated from the graphs)

- **Dry density:** 395 ± 10 kg·m^{-3}[1]
- **Heat capacity:** 1880 J·kg^{-1}·K^{-1}[2]
- **Porosity:** **≈ 0.8 m3·m^{-3}**
- **Thermal conductivity of the dry material:**

Test Method	T, Hot surface °C	T, Cold surface °C	Mean Temperature °C	Orientation	λ W·m^{-1}·K^{-1}
***				longitudinal	0.25[3]
***				transversal	0.1[3]

- **Sorption/desorption curve[4]:**

Relative humidity %	Sorption moisture content kg•kg^{-1}	Desorption moisture content kg•kg^{-1}
20.5	0.053	
43.8	0.090	
44.2	0.085	
65.2	0.125	
65.5	0.121	
87.7	0.178	
86.0	0.183	
95.4	0.247	

Relative humidity %	Sorption moisture content kg•kg^{-1}	Desorption moisture content kg•kg^{-1}
95.6	0.252	
98.5	0.304	
98.7	0.308	
20.2		0.063
20.5		0.061
45.1		0.110
45.3		0.112
65.1		0.0148
65.4		0.0151
80.0		0.200
80.3		0.199
89.8		0.245
90.0		0.243
95.1		0.279
95.6		0.276

- **Water Vapour Permeability (from cup method) at 25 °C[5]:**

Mean RH %	Orientation	Water vapour permeability kg·m^{-1}·s^{-1}·Pa^{-1}
20	longitudinal	5.3 E-11
40	"	7.4E-11
60	"	8.4E-11
80	"	8.6E-11
95	"	8.7E-11
20	transversal	5.3E-13
40	"	1.1E-12
60	"	2.6E-12
80	"	7.6E-12
95	"	1.7E-11

- **Moisture diffusivity at 20 °C, longitudinal[1]:**

Moisture content (kg•kg^{-1})	Moisture Diffusivity (m^2·s^{-1})
0.101	5.7E-10
0.152	3.3E-10
0.202	2.2E-10
0.253	1.6E-10
0.303	1.2E-10
0.354	1.0E-10
0.404	9.2E-11

Moisture content ($kg \cdot kg^{-1}$)	Moisture Diffusivity ($m^2 \cdot s^{-1}$)
0.455	8.7E-11
0.505	8.5E-11
0.556	8.7E-11
0.606	9.0E-11
0.657	1.0E-10
0.758	1.1E-10
0.808	1.3E-10
0.960	1.3E-10
1.010	1.4E-10
1.162	1.4E-10
1.212	1.4E-10
1.263	1.3E-10
1.313	1.3E-10
1.364	1.2E-10
1.414	1.2E-10
1.465	1.1E-10
1.515	1.1E-10
1.566	1.1E-10
1.616	1.2E-10
1.667	1.2E-10
1.717	1.4E-10
1.768	1.6E-10
1.818	2.7E-10
1.919	3.9E-10

- **Water Absorption Coefficient:** 0.0096 $kg \cdot m^{-2} \cdot s^{-1/2}$; longitudinal[1]

2.9 Plywood

- **SOURCES**

[1] Catalogue of Material properties(upgraded version), Report Annex XIV, Page 2.18

[2] Richards, R. F., Burch, D. M. and Thomas, W. C. Water Vapor Sorption Measurements of Common Building Materials. ASHRAE Transactions, 1992, V.98, Pt. 2.

[3] Institute for Research in Construction, NRC Canada, data.

[4] Institute for Research in Construction data from an IEA common exercise; density of the specimen = 511.5 $kg\cdot m^{-3}$

[5] Kurt Kielsgaard Hansen, Sorption Isotherms, A Catalogue, The Technical University of Denmark, Technical Report 162/86; the data corresponds to a plywood sample with a density = 600 $kg\cdot m^{-3}$; the data originally appeared in Tech. Report 36, Lund Inst. of Technology by Ahlgren Lennart, 1972.

[6] Galbraith G. H., McLean, R. C.' Vapour permeability testing', Final report to the Building Research Establishment; Contract F3/2/490, Strathclyde University, June 1993.

[7] Calculated using the equation reported by Burch, D. M., Thomas, W. C. and Fanney, A. H.; ASHRAE Transactions 1992, V.98, Pt.2.

[8] Data from CMHC, Canada, report on "Air permeance of building materials"; specimens were 1 m x 1 m and 8 mm thick.

- **Dry density:** 445 to 799 $kg\cdot m^{-3}$[1]
  509 $kg\cdot m^{-3}$[2]
  500 to 600 $kg\cdot m^{-3}$[3]
- **Heat capacity:** 1880 $J\cdot kg^{-1}\cdot K^{-1}$[1]

- **Thermal conductivity of the dry material:**

Test Method	T, Hot surface °C	T, Cold surface °C	Mean Temperature °C	λ $W\cdot m^{-1}\cdot K^{-1}$
ASTM C518	35	13	24	0.09 to 0.111[3]
ASTM C518	34.94	13.46		0.109[4]

Reference[1] gives the following equation:

$$\lambda = 0.0201 + 1.66 \times 10^{-4}\ \rho \qquad (\rho = 445 \text{ to } 692\ kg\cdot m^{-3})$$

- **Thermal conductivity of moist material :**

Reference[1] gives the following equation:

$$\lambda = 0.113 + 3.14 \times 10^{-4}\ w$$

- **Sorption/desorption curve[5]:**

Relative humidity %	**Sorption moisture content $kg \cdot kg^{-1}$**	**Desorption moisture content $kg \cdot kg^{-1}$**
20.2	0.061	
20.2	0.064	
42.7	0.095	
43.2	0.096	
64.9	0.127	
65.1	0.130	
84.8	0.179	
85.2	0.180	
94.6	0.234	
94.9	0.237	
96.9	0.272	
97.3	0.276	
20.1		0.074
20.4		0.072
44.3		0.116
44.6		0.116
65.0		0.156
65.2		0.154
79.5		0.199
79.8		0.196
89.7		0.245
90.1		0.238
94.6		0.263
94.8		0.282

- **Sorption/desorption curve[2]:**

Relative humidity %	**Sorption moisture content $kg \cdot kg^{-1}$**	**Desorption moisture content $kg \cdot kg^{-1}$**
11.3	0.017	0.024
32.8	0.046	0.062
43.2	0.054	0.078
57.6	0.071	0.104

Relative humidity %	Sorption moisture content kg•kg^{-1}	Desorption moisture content kg•kg^{-1}
78.6	0.109	0.148
84.3	0.139	0.178
93.6	0.188	0.222
97.3	0.242	0.283

Reference[1] gives the following equations for sorption:

$$w(kg\cdot m^{-3}) = 75[1 - \ln \varphi / 0.00614]^{-1/1.91} \text{ or}$$
$$= \varphi / (-0.119\, \varphi^2 + 0.136\, \varphi + 0.029)$$

and the following equations for desorption:

$$w(kg\cdot m\text{-}3) = 75[1 - \ln \varphi / 0.00963]^{-1/1.93} \text{ or}$$
$$= \varphi / (-0.074\, \varphi^2 + 0.088\, \varphi + 0.026)$$

- **Water Vapour Permeability (from cup method):**

RH(1) %	RH(2) %	Mean RH %	Water vapour permeability kg·m^{-1}·s^{-1}·Pa^{-1} x 10^{-13}
		54	19[1]
		86	79[1]
0	50		1.47 to 4.74[3]
0	50		2.7[4]
0	76.6		5.8[4]
50	100		50[4]
76.3	100		98[4]
0	60		5.5[6]
60	80		19.0[6]
60	93		44.8[6]
60	100		65.3[6]
		20	11[7]
		40	8.6[7]
		60	14[7]
		80	48[7]
		90	110[7]
		95	190[7]

- **Moisture diffusivity** :

Reference[1] gives the following equation:

$$D_W = 3.2 \times 10^{-13} \exp(0.015\, w)$$

- **Water Absorption Coefficient:** 0.003 kg·m^{-2}·s$^{-½}$[1]

- **Air permeability[8]:**

Pressure difference Pa	Permeability $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1} x 10^{-10}$
25	8.9
50	8.6
75	8.4
100	8.3

2.10 Wood Fibreboard

- SOURCES

[1] Institute for Research in Construction, NRC, Canada, data.

[2] Kurt Kielsgaard Hansen, Sorption Isotherms, A Catalogue, The Technical University of Denmark, Technical Report 162/86; the data corresponds to a porous board sample with a density = 300 kg·m^{-3}; the data originally appeared in Tech. Report 36, Lund Inst. of Technology by Ahlgren Lennart, 1972.

[3] Richards, R. F., Burch, D. M. and Thomas, W. C. Water Vapor Sorption Measurements of Common Building Materials. ASHRAE Transactions, 1992, V.98, Pt. 2; sample density 266 kg·m^{-3}.

[4] VTT, Finland, data; sample density 340 kg·m^{-3}.

[5] Calculated using the equation reported by Burch, D. M., Thomas, W. C. and Fanney, A. H.; ASHRAE Transactions 1992, V.98, Pt.2.

[6] Institute for Research in Construction, NRC, Canada, data on a specimen with density 243 kg·m^{-3}.

[7] Data from CMHC Canada report on "Air permeance of building materials"; specimens were 1 m x 1 m and 11 mm thick.

- **Dry density:** 240 to 380 kg·m^{-3}[1]

- **Thermal conductivity of the dry material:**

Test Method	**T,Hot surface °C**	**T, Cold surface °C**	**Mean Temperature °C**	**λ W·m^{-1}·K^{-1}**
ASTM C518	35	13	24	0.0485 to 0.0588[1]

- **Sorption/desorption curve[2]:**

Relative humidity %	Sorption moisture content $kg \cdot kg^{-1}$	Desorption moisture content $kg \cdot kg^{-1}$
20.1	0.050	
20.4	0.056	
42.8	0.080	
43.0	0.082	
64.5	0.112	
64.9	0.118	
84.2	0.166	
84.6	0.168	
94.2	0.239	
94.5	0.241	
97.6	0.334	
97.8	0.338	
20.3		0.062
20.4		0.061
44.9		0.100
44.9		0.102
64.6		0.143
65.0		0.144
79.0		0.185
79.4		0.183
89.2		0.243
89.4		0.239
94.0		0.330
94.4		0.360

- **Sorption/desorption curve[3]:**

Relative humidity %	Sorption moisture content $kg \cdot kg^{-1}$	Desorption moisture content $kg \cdot kg^{-1}$
11.3	0.019	0.017
32.8	0.047	0.054
43.2	0.062	0.068
57.6	0.080	0.094
78.6	0.117	0.141
84.3	0.138	0.167
93.6	0.189	0.227
97.3	0.245	0.278

- **Sorption Curve**[4]:

Relative humidity **%**	**Sorption moisture content** **$kg \cdot kg^{-1}$**
25	0.033
50	0.056
70	0.07
90	0.104

- **Water Vapour Permeability (from cup method):**

RH(1) **%**	**RH(2)** **%**	**Mean RH** **%**	**Water vapour permeability** **$kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1} \times 10^{-11}$**
0	50		0.85 to 2.7[1]
		25	1.6[4]
		50	2.0[4]
		75	3.6[4]
		95	5.8[4]
		20	6.8[5]
		40	3.9[5]
		60	2.8[5]
		80	2.6[5]
		90	2.7[5]
		95	2.8[5]

- **Moisture diffusivity[6]** :

Moisture Content **$kg \cdot kg^{-1}$**	**Moisture diffusivity** **$m^2 \cdot s^{-1}$**
0.02	5.1E-10
0.05	1.0E-09
0.07	1.7E-09
0.10	2.3E-09
0.11	2.5E-09
0.16	2.0E-09
0.19	1.4E-09
0.23	8.7E-10
0.24	7.8E-10
0.32	4.8E-10
0.52	2.9E-10
0.77	3.6E-10
1.01	4.5E-10
1.23	5.8E-10
1.41	8.1E-10

Moisture Content $kg \cdot kg^{-1}$	**Moisture diffusivity** $m^2 \cdot s^{-1}$
1.51	1.2E-09
1.57	2.4E-09
1.58	3.1E-09
1.59	4.7E-09
1.59	9.4E-09

- **Air permeability[7]:**

Pressure difference Pa	**Permeability** $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1} x10^{-7}$
25	1.45
50	1.45
75	1.45
100	1.44

2.11 Wafer Board Or Wood-Chip Board

- SOURCES

[1] Institute for Research in Construction, NRC, Canada,data.

[2] Richards, R. F., Burch, D. M. and Thomas, W. C. Water Vapor Sorption Measurements of Common Building Materials. ASHRAE Transactions, 1992, V.98, Pt. 2; sample density 266 kg·m^{-3}.

[3] Data from CMHC, Canada, report on "Air permeance of building materials"; specimens were 1 m x 1 m and 11 mm thick.

[4] Data from CMHC, Canada, report on "Air permeance of building materials"; specimens were 1 m x 1 m and 16 mm thick.

- **Dry density:** ≈ 700 kg·m^{-3}
- **Heat capacity:** = 1880 J·kg^{-1}·K^{-1}
- **Thermal conductivity of the dry material:**

Test Method	T,Hot surface °C	T, Cold surface °C	MeanTemperature °C	λ W·m^{-1}·K^{-1}
ASTM C518	35	13	24	0.105[1]

- **Sorption/desorption curve[2]:**

Relative humidity %	Sorption moisture content kg•kg^{-1}	Desorption moisture content kg•kg^{-1}
11.3	0.025	0.024
32.8	0.030	0.053
43.2	0.037	0.064
57.6	0.052	0.086
78.6	0.087	0.121
84.3	0.110	0.146
93.6	0.156	0.208
97.3	0.199	0.237

- **Water Vapour Permeability (from cup method):**

RH(1) %	RH(2) %	Mean RH %	Water vapour permeability kg·m^{-1}·s^{-1}·Pa^{-1} x 10^{-13}
0	50		3.0 to 5.0[1]

- **Air permeability[3]:**

Pressure difference Pa	Permeability $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1} x10^{-9}$
25	1.9
50	1.9
75	1.9
100	1.9

- **Air permeability[4]:**

Pressure difference Pa	Permeability $kg \cdot m^{-1} s^{-1} Pa^{-1} x10^{-9}$
25	1.8
50	1.8
75	1.8
100	1.8

2.12 Particle Board

- **SOURCES**

[1] Catalogue of Material properties(upgraded version), Report Annex XIV, Page 2.17

[2] VTT, Finland, data.

[3] Richards, R. F., Burch, D. M. and Thomas, W. C. Water Vapor Sorption Measurements of Common Building Materials. ASHRAE Transactions, 1992, V.98, Pt. 2; the material is identified as: particle board, 19 mm thick and density = 762 $kg{\cdot}m^{-3}$.

[4] Data from CMHC, Canada, report on "Air permeance of building materials"; specimens were 1 m x 1 m and 16 mm thick.

- **Dry density:** ≈ 570 to 800 $kg{\cdot}m^{-3}$
- **Heat capacity[1]:** = 1880 $J{\cdot}kg^{-1}{\cdot}K^{-1}$
- **Porosity[2]**: ≈ 0·48 $m^3{\cdot}m^{-3}$

- **Thermal conductivity:**

Reference[1] gives the following equation at a mean temperature of 20 °C, for the dry material:

$$\lambda,\ W{\cdot}m^{-1}{\cdot}K^{-1} = 0.098 + 0.0001(\rho - 590)$$

where ρ is density.

Reference[1] gives the following equation at a mean temperature of 20 °C, for the moist material:

$$\lambda,\ W{\cdot}m^{-1}{\cdot}K^{-1} = 0.106 + 1.31 \times 10^{-4}\, w + 3.28 \times 10^{-7}\, w^2$$

where w is the moisture content, $kg{\cdot}m^{-3}$.

- **Sorption/desorption curve[2]:**

Relative humidity %	**Sorption moisture content $kg{\cdot}kg^{-1}$**
25	0.037
50	0.046
75	0.060
90	0.092

- **Sorption/desorption curve[3]:**

Relative humidity %	Sorption moisture content $kg \cdot kg^{-1}$	Desorption moisture content $kg \cdot kg^{-1}$
11.3	0.012	0.017
32.8	0.039	0.053
43.2	0.047	0.074
57.6	0.063	0.088
78.6	0.097	0.140
84.3	0.113	0.166
93.6	0.159	0.190
97.3	0.215	0.233

Reference[1] gives the following equations for sorption:

$$u\ (kg \cdot kg^{-1}) = 0.35[1 - \ln \varphi / 0.0328]^{-1/1.89} \quad \text{or}$$

$$= \varphi \times 10^{-2} / (-0.157\ \varphi^2 + 0.183\ \varphi + 0.016)$$

Reference[1] gives the following equations for desorption:

$$u\ (kg \cdot kg^{-1}) = 0.35[1 - \ln \varphi / 0.0808]^{-1/1.63} \quad \text{or}$$

$$= \varphi \times 10^{-2} / (-0.054\ \varphi^2 + 0.074\ \varphi + 0.026)$$

The relative humidity, φ in the above equations is expressed as a fraction.

- **Critical moisture content[1]** 0.85 $kg \cdot kg^{-1}$
- **Capillary moisture content[1]** 0.90 $kg \cdot kg^{-1}$
- **Maximum moisture content[1]** 0.99 $kg \cdot kg^{-1}$
- **Water Vapour Permeability (from cup method)[2]:**

RH(1) %	RH(2) %	Mean RH %	Water vapour permeability $kg.m^{-1}.s^{-1}.Pa^{-1} \times 10^{-12}$
		25	4.4
		50	6.0
		75	10.2
		95	15.2

Reference [1] gives the following equation for vapour permeability:

$$\delta = A \times 10^{-10} \exp(B\rho)$$

with the following values for the constants A and B at two different mean RH's.

RH, %	A	B
25	3.50	- 0.00757
86	3.74	- 0.00676

Reference [3] gives the following equation for vapour permeability at 7 and 24 °C:

$$\delta = \mathrm{Exp}(-25.520 - 3.2984\ \varphi + 3.8167\ \varphi^2)$$

as a function of the relative humidity φ (%).

- **Moisture diffusivity at 20 °C[2]:**

u, $(kg \cdot kg^{-1})$	0.1	0.25	0.5	1.0
D_W, $(m^2 \cdot s^{-1})$	1.4E-9	4.0E-9	5.0E-9	3.0E-9

- **Air permeability[4]:**

Pressure difference Pa	**Permeability $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1} x10^{-9}$**
25	7.1
50	6.8
75	6.7
100	6.6

2.13 Polystyrene Concrete

- SOURCE

[1] Catalogue of Material properties (upgraded version), Report Annex XIV, Page 2.5

- **Dry density:** ≈ 260 to 800 $kg{\cdot}m^{-3}$

- **Heat capacity[1]:** = 1020 to 1370 $J{\cdot}kg^{-1}{\cdot}K^{-1}$

- **Thermal conductivity:**

Reference[1] gives the following equation at a mean temperature of 20 °C, for the dry material:

$$\lambda,\ W{\cdot}m^{-1}{\cdot}K^{-1} = 0.041\ \exp(0.002317\rho)$$

where ρ is density.

Reference[1] gives the following equation at a mean temperature of 20 °C, for the moist material, for the whole dry density range:

$$\lambda,\ W{\cdot}m^{-1}{\cdot}K^{-1} = A + B\ w$$

where w is the moisture content ≤ 200 $kg{\cdot}m^{-3}$; the constants A and B are given below.

density, $kg{\cdot}m^{-3}$	A	B
260 - 335	0.074	4.83×10^{-4}
357 - 382	0.111	4.61×10^{-4}
407 - 456	0.126	6.06×10^{-4}
641	0.151	7.89×10^{-4}
792	0 .213	1.04×10^{-3}

- **Sorption curve:**

Reference[1] gives the following equations for sorption, for a sample with density 422 $kg{\cdot}m^{-3}$:

$$w(\ kg{\cdot}m^{-3}) = 235[1 - \ln \varphi / 0.0097]^{-1/1.55} \text{ or}$$
$$= \varphi / (-0.007\ \varphi^2 - 0.039\ \varphi + 0.056)$$

The relative humidity, φ in the above equations is expressed as a fraction.

- **Maximum moisture content[1]** 489 $kg{\cdot}m^{-3}$

- **Water Vapour Permeability (from cup method):**

Reference [1] gives the following equation for vapour permeability:

$$\delta = 1.55 \times 10^{-11} + 6.00 \times 10^{-13} \exp(2.88\varphi)$$

- **Moisture diffusivity[1]:**

$$D_w,\ (m^2{\cdot}s^{-1}) = 4.6 \times 10^{-10} \exp(0.064\ w)$$

2.14 Polymer-Modified Glassfibre Cement

- SOURCE

[1] Laboratory of Building Physics, KU-Leuven, Belgium, data.

- **Dry density[1]** 2000 kg·m^{-3}
- **Sorption curve[1]:**

Relative humidity %	Sorption moisture content kg•kg^{-1}
33	0.014
52	0.021
75	0.034
86	0.043
97	0.098
99.8	0.11

- **Capillary moisture content[1]** 0.098 kg•kg^{-1}
- **Maximum moisture content[1]** 0.113 kg•kg^{-1}
- **Water Vapour Permeability (from cup method)[1]:**

RH(1) %	RH(2) %	Water vapour permeability kg·m^{-1}·s^{-1}·Pa^{-1} x 10 $^{-12}$
0.0	52	0.88
52	86	1.1
86	97	2.7

2.15 Sand-Lime Stone

- SOURCE

[1] Catalogue of Material properties (upgraded version), Report Annex XIV, Page 2.8

- **Dry density[1]:** = 1685 to 1807 $kg{\cdot}m^{-3}$
- **Heat capacity[1]:** = 840 $J{\cdot}kg^{-1}{\cdot}K^{-1}$
- **Sorption/Desorption curves[1]:**

Reference[1] gives the following equations for sorption, for samples with density 1685 to 1726 $kg{\cdot}m^{-3}$:

$$w(\,kg{\cdot}m^{-3}) = 210[1 - \ln \varphi / 0.00356]^{-1/2.39} \text{ or}$$
$$= \varphi / (-0.033\, \varphi^2 - 0.039\, \varphi + 0.009)$$

Reference[1] gives the following equations for desorption, for samples with density 1685 to 1726 $kg{\cdot}m^{-3}$:

$$w\,(\,kg{\cdot}m^{-3}) = 330[1 - \ln \varphi / 0.00658]^{-1/1.81} \text{ or}$$
$$= \varphi / (-0.045\, \varphi^2 - 0.044\, \varphi + 0.011)$$

- **Critical moisture content[1]** 120 $kg{\cdot}m^{-3}$
- **Capillary moisture content[1]** 233 $kg{\cdot}m^{-3}$
- **Water Vapour Permeability (from cup method):**

Reference [1] gives the following equation for vapour permeability:

$$\delta = 8.19 \times 10^{-12} + 8.66 \times 10^{-15} \exp(9.86\varphi)$$

The relative humidity, φ in all the above equations is expressed as a fraction.

- **Moisture diffusivity[1]:**

$$Dw,\ (m^2{\cdot}s^{-1}) = \ 2.2 \times 10^{-10} \exp(0.027\ w)$$

2.16 Wood Wool Cement Board

- SOURCES

[1] Catalogue of Material properties (upgraded version), Report Annex XIV, Page 2.19

[2] IRC, Canada, data on a sample with density 412 kg·m^{-3} and thickness 23.4 mm.

[3] Laboratory of Building Physics, KU-Leuven, Belgium, data;density of specimen 320.5 kg·m^{-3} and thickness 47.6 mm.

- **Dry density[1]** 300 to 800 kg·m^{-3}

- **Heat capacity[1]** 1880 J·kg^{-1}·K^{-1}

- **Thermal conductivity of the dry material**

Test Method	T,Hot surface °C	T, Cold surface °C	Temperature °C	λ W·m^{-1}·K^{-1}
ASTM C518	34.84	13.0		0.0708[2]
***	***	***	1.6	0.0555[3]
***	***	***	11.54	0.058[3]
***	***	***	21.43	0.0595[3]
***	***	***	31.3	0.063[3]

- **Thermal conductivity of moist material[1]**

For samples with density 314 to 394 kg·m^{-3}, Reference[1] gives the following equation:

$$\lambda,\ \mathrm{W\cdot m^{-1}\cdot K^{-1}} = 0.0632 + 3.95 \times 10^{-4}\, w$$

- **Sorption/desorption curve:**

Relative humidity %	Sorption moisture content kg•kg^{-1}	Desorption moisture content kg•kg^{-1}
33	0.036	0.052[3]
52	0.068	0.097[3]
75	0.094	0.140[3]
86	0.145	0.215[3]
97	0.224	0.607[3]
99.8	0.251	0.706[3]
50	0.043[2]	

Reference[1] gives the following equations for sorption and desorption, for samples with density 767 kg·m^{-3}:

$$w\ (\mathrm{kg \cdot kg^{-1}}) = 0.15[1 - \ln \varphi / 0.172]^{-1/0.84} \text{ or}$$
$$= \varphi \times 10^{-2} / (-0.278\,\varphi^2 - 0.588\,\varphi + 0.421)$$

- **Capillary moisture content[3]** 0.569 $\mathrm{kg \cdot kg^{-1}}$
- **Maximum moisture content[3]** 0.875 $\mathrm{kg \cdot kg^{-1}}$
- **Water Vapour Permeability (from cup method):**

RH(1) %	**RH(2) %**	**Mean RH %**	**Water vapour permeability $\mathrm{kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1}} \times 10^{-11}$**
0	50		3.3[2]
0	76.6		3.3[2]
50	100		3.6[2]
76.3	100		4.1[2]
0.0	52		3.1[3]
52	86		4.3[3]
86	97		12.0[3]

- **Moisture diffusivity[1]**:

$$D_w,\ (\mathrm{m^2 \cdot s^{-1}}) = 6.2 \times 10^{-12} \exp(0.027\, w)$$

- **Air permeability[3]:**

Pressure Pa	**Permeability $\mathrm{kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1}} \times 10^{-4}$**
10	5.0
20	5.1
30	5.2
40	5.3
50	5.4
60	5.5
70	5.5
80	5.6
90	5.7

2.17 Fibre Cement

- SOURCES

[1] Catalogue of Material properties (upgraded version), Report Annex XIV, Page 2.8

[2] Laboratory of Building Physics, KU-Leuven, Belgium, data; density of specimen 973.2 kg·m^{-3} and thickness 18.2 mm.

- **Dry density[1]:** = 820 to2050 kg·m^{-3}
- **Heat capacity[1]:** = 840 J·kg^{-1}·K^{-1}
- **Thermal conductivity of the dry material[2]:**

Test Method	T,Hot surface °C	T, Cold surface °C	Temperature °C	λ W·m^{-1}·K^{-1}
B62-003	***	***	1.65	0.184
"	***	***	11.09	0.186
"	***	***	21.38	0.188
"	***	***	31.31	0.191

Thermal conductivity of moist material at 20 °C:

Reference[1] gives the following equations:

For samples with densities 823 to 862 kg·m^{-3} ,

$$\lambda,\ \mathrm{W{\cdot}m^{-1}{\cdot}K^{-1}} = 0.14 + 5.8 \times 10^{-4}\, w$$

and for samples with densities 1495 kg·m^{-3} ,

$$\lambda,\ \mathrm{W{\cdot}m^{-1}{\cdot}K^{-1}} = 0.42 + 1.2 \times 10^{-3}\, w.$$

- **Sorption/desorption curve:**

Relative humidity %	Sorption moisture content kg•kg^{-1}	Desorption moisture content kg•kg^{-1}
33	0.026	0.049[2]
52	0.054	0.075[2]
75	0.067	0.152[2]
86	0.101	0.257[2]
97	0.268	0.549[2]
99.8	0.317	0.563[2]

Reference[1] gives the following equations for sorption, for samples with density 990 kg.m^{-3}:

$$w(\mathrm{kg.m^{-3}}) = 300[1 - \ln\varphi / 0.0077]^{-1/1.93} \text{ or}$$
$$= \varphi / (-0.473\,\varphi^2 - 0.541\,\varphi + 0.015)$$

Reference[1] gives the following equations for desorption, for samples with density 990 kg.m^{-3}:

$$w(\mathrm{kg.m^{-3}}) = 358[1 - \ln\varphi / 0.00415]^{-1/1.36} \text{ or}$$
$$= \varphi / (-0.508\,\varphi^2 + 0.514\,\varphi + 0.041)$$

- **Critical moisture content[1]**	350 kg.m^{-3}	density 840 kg.m^{-3}
- **Capillary moisture content[1]**	358 kg·m^{-3}	density 1495 kg·m^{-3}
- **Capillary moisture content[1]**	430 kg·m^{-3}	density 1495 kg·m^{-3}

- **Water Vapour Permeability (from cup method):**

RH(1) %	**RH(2) %**	**Mean RH %**	**Water vapour permeability kg·m^{-1}·s^{-1}·Pa^{-1} x 10 $^{-11}$**
0.0	52		0.46[2]
52	86		0.98[2]
86	97		6.8[2]

Reference [1] gives the following equations for vapour permeability:

$\delta = 1.07 \times 10^{-11} + 1.06 \times 10^{-14} \exp(7.85\varphi)$	density 840 kg·m^{-3}
$\delta = 1.22 \times 10^{-11} + 2.66 \times 10^{-14} \exp(4.92\varphi)$	density 1495 kg·m^{-3}

The relative humidity, φ in all the above equations is expressed as a fraction.

- **Moisture diffusivity[1]:**

$$D_{w}, (\mathrm{m^2 \cdot s^{-1}}) = 3.4 \times 10^{-11} \exp(0.018\, w)$$

- **Air permeability[2]:**

Pressure **Pa**	**Permeability** **$kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1} x 10^{-9}$**
10	9.9
20	9.1
30	8.7
40	8.4
50	8.2
60	8.0
70	7.9
80	7.8
90	7.7

2.18 Glass Fibre Insulation

- **SOURCES**

[1] Institute for Research in Construction, NRC, Canada, data.

[2] Catalogue of Material properties (upgraded version), Report Annex XIV, Page 2.23

[3] Institute for Research in Construction, NRC, Canada, data, according to ASTM Standard C177.

[4] Laboratory of Building Physics, KU-Leuven, Belgium, data, according to Belgian standard B62-003.

[5] Hokoi, S and M. K. Kumaran, Journal of Thermal Insulation and Building Envelopes, p. 263-292, Vol 16, 1993.

[6] [6]Kurt Kielsgaard Hansen, Sorption Isotherms, A Catalogue, The Technical University of Denmark, Technical Report 162/86; the data corresponds to a concrete sample with the following specifications: density = 18 kg·m^{-3}; the data originally appeared in Tech. Report 36, Lund Inst. of Technology by Ahlgren Lennart, 1972.

[7] Kumaran, M. K. Temperature dependence of water vapour permeability of glassfibre insulation from heat flow measurements; CIB W40 Meeting, 1993.

[8] Data from CMHC Canada report on "Air permeance of building materials"; specimens were m x 1 m.

- **Dry density[1]** 8 to 180 kg·m^{-3}
- **Heat capacity[2]** 840 J·K^{-1}·kg^{-1}
- **Thermal conductivity of the dry material at 24 °C as a function of density[1] according to ASTM Standard C518:**

Density kg·m^{-3}	Thickness mm	λ W·m^{-1}·K^{-1}	Density kg·m^{-3}	Thickness mm	λ W·m^{-1}·K^{-1}
7.7	146	0.0483	38.1	50.7	0.0333
9.9	128	0.0473	44.4	38	0.0326
10.3	144	0.0455	53.4	24	0.0322
11.4	153	0.0450	60.7	50	0.0332
12.8	152	0.0427	68.6	50	0.0319
13.1	89	0.0424	71.0	50	0.0324
14.7	90	0.0412	135.0	26.4	0.0328

Reference[2] gives the following equation at 20 °C:

$$\lambda\ (\mathrm{W\cdot m^{-1}\cdot K^{-1}}) = 0.02675 + 4.85\times10^{-5}\,\rho + 0.178/\rho$$

- **Temperature dependence of thermal conductivity:**

Specimen 1[3]: Density = 8.3 kg·m^{-3}, thickness = 152 mm

T,Hot surface °C	T, Cold surface °C	Temperature °C	λ W·m^{-1}·K^{-1}
12.68	-10.73	0.98	0.0472
22.61	1.20	11.90	0.0515
35.20	12.96	24.08	0.0552
45.89	25.21	35.55	0.0592
58.76	39.55	49.16	0.0662

Specimen 2[4]: Density = 18.1 kg·m^{-3}, thickness = 100 mm

T,Hot surface °C	T, Cold surface °C	Temperature °C	λ W·m^{-1}·K^{-1}
16.1	5.9	11.0	0.0326
25.8	15.6	20.7	0.0347
35.7	25.6	30.7	0.0364

Specimen 3[4]: Density = 43.4 kg·m^{-3}, thickness = 50 mm

T,Hot surface °C	T, Cold surface °C	Temperature °C	λ W·m^{-1}·K^{-1}
4.7	-5.2	-0.25	0.0306
14.5	5.2	9.9	0.0319
24.4	15.3	19.9	0.0333
34.3	25.2	29.8	0.0344

Specimen 4[3]: Density = 53.7 kg·m^{-3}, thickness = 26.3 mm

T,Hot surface °C	T, Cold surface °C	Temperature °C	λ W·m^{-1}·K^{-1}
12.39	-11.13	0.63	0.0295
24.51	2.26	13.39	0.0311
35.20	13.36	24.28	0.0322
45.80	24.97	35.38	0.0338
57.60	37.01	47.31	0.0360

Specimen 5[3]: Density = 151 kg·m^{-3}, thickness = 25.6 mm

T,Hot surface °C	T, Cold surface °C	Temperature °C	λ W·m^{-1}·K^{-1}
24.11	-4.06	10.02	0.0320
37.06	9.02	23.04	0.0332
54.35	26.23	40.29	0.0351

Specimen 6[4]: Density = 152.9 kg·m^{-3}, thickness = 49.2 mm

T,Hot surface °C	T, Cold surface °C	Temperature °C	λ W·m^{-1}·K^{-1}
5.2	-4.4	0.4	0.0357
15.0	6.0	10.5	0.0372
25.0	16.0	20.5	0.0380
34.8	26.0	30.4	0.0393

- **Thermal conductivity of moist material:**

Reference[5] suggests the following equation:

$$\lambda(\psi) = \lambda_0 + (\lambda_w - \lambda_0)[(\psi - 0.1)/0.88]^2$$

where ψ is the moisture content expressed as m^3·m^{-3}, λ_0 is the thermal conductivity of dry material and λ_w is the thermal conductivity of water.

- **Sorption/desorption curve[6]:**

Relative humidity %	Sorption moisture content $kg \cdot kg^{-1}$	Desorption moisture content $kg \cdot kg^{-1}$
20.4	0.0087	
43.4	0.012	
64.5	0.014	
84.9	0.017	
95.1	0.019	
98.0	0.026	
20.0		0.01
43.1		0.014
64.8		0.017
84.4		0.022
94.5		0.029
97.6		0.042

- **Water Vapour Permeability (from cup method)[1] at 23 °C:**

Specimen density $kg \cdot m^{-3}$	RH(1) %	RH(2) %	Water vapour permeability $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1}$ x 10^{-10}
16.8	53	0	1.32
16.8	53	0	1.41
35.2	50.2	0	1.65
37.3	50.2	0	1.35
35.0	50.2	0	1.22
72.0	52.4	0	1.15
74.3	52.4	0	1.15
67.3	52.4	0	1.16
119.8	51.4	0	1.27
108.9	51.4	0	1.23
119.1	51.4	0	1.35

Reference[2] reports that for glassfibre insulation with densities 19 to 102 $kg \cdot m^{-3}$ the water vapour permeability is 1.58×10^{-10} $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1}$.

Reference[7] suggests the following expression for the temperature (θ, °C) dependence of water vapour permeability, with the vapour pressure approaching saturation level:

$$\delta_p \, (kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1}) = 1.59 \times 10^{-10} + 8.87 \times 10^{-13} \theta$$

- **Air permeability:**

Specimen 1[4]: Density = 17.9 $kg \cdot m^{-3}$, thickness = 120 mm; flow ⊥ to fibre orientation

Pressure difference Pa	Permeability $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1} x10^{-4}$
0.05	1.55
0.1	1.41
0.15	1.35
0.2	1.3
0.25	1.27
0.3	1.24

Specimen 2[4]: Density = 42.0 kg·m^{-3}, thickness = 50 mm; flow ⊥ to fibre orientation

Pressure difference Pa	Permeability $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1} x10^{-5}$
0.05	6.59
0.1	6.42
0.15	6.31
0.2	6.25
0.25	6.19
0.3	6.15

Specimen 3[3]: Density = 147.2 kg·m^{-3}, thickness = 50 mm; flow ⊥ to fibre orientation

Pressure difference Pa	Permeability $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1} x10^{-5}$
0.1	2.49
0.2	2.45
0.3	2.43
0.4	2.47
0.5	2.40
0.6	2.39
0.7	2.38

Specimen 4[8]: Density ≈ 20 kg·m^{-3}, thickness = 152 mm

Pressure difference Pa	Permeability $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1} x10^{-5}$
25	9.5
50	9.1
75	8.9
100	8.8

2.19 Mineral Fibre Insulation

- SOURCES

[1]Catalogue of Material properties (upgraded version), Report Annex XIV, Page 2.24

[2]Institute for Research in Construction, NRC, Canada, data.

[3]Laboratory of Building Physics, KU-Leuven, Belgium, data, according to Belgian standard B62-003.

[4]Kurt Kielsgaard Hansen, Sorption Isotherms, A Catalogue, The Technical University of Denmark, Technical Report 162/86; the data corresponds to a sample with the following specifications: density = 42 kg·m^{-3}; the data originally appeared in Tech. Report 36, Lund Inst. of Technology by Ahlgren Lennart, 1972.

- **Dry density[1]** 30 to 190 kg·m^{-3}

- **Heat capacity[1]** 840 J·K^{-1}·kg^{-1}

- **Thermal conductivity of the dry material as a function of density:**

Reference[1] gives the following equations at 10 and 20 °C:

$$\lambda\ (W\cdot m^{-1}\cdot K^{-1}) = 0.02606 + 5.48\times10^{-5}\rho + 0.331/\rho$$

$$\lambda\ (W\cdot m^{-1}\cdot K^{-1}) = 0.03167 + 2.64\times10^{-5}\rho + 0.206/\rho$$

- **Temperature dependence of thermal conductivity:**

Specimen 1[2]: Density = 35.9 kg·m^{-3}, thickness = 140 mm

T,Hot surface °C	T, Cold surface °C	Temperature °C	λ W·m^{-1}·K^{-1}
1.16	-21.56	-10.20	0.0303
21.23	-0.80	10.21	0.0340
34.84	12.94	23.89	0.0365

Specimen 2[3]: Density = 155 kg·m^{-3}, thickness = 48 mm

Temperature °C	λ W·m^{-1}·K^{-1}
1.7	0.036
11.5	0.037
21.4	0.038
31.3	0.039

- **Sorption/desorption curve[4]:**

Relative humidity %	**Sorption moisture content $kg \cdot kg^{-1}$**	**Desorption moisture content $kg \cdot kg^{-1}$**
20.1	0.005	
43.4	0.0055	
65.0	0.0059	
85.2	0.007	
94.5	0.0076	
97.5	0.008	
20.1		0.005
44.9		0.0058
64.9		0.0063
84.5		0.0081
94.7		0.011
97.8		0.016

- **Water Vapour Permeability (from cup method)[3] at 23 °C:**

RH(1) %	**RH(2) %**	**Water vapour permeability $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1} \times 10^{-11}$**
52	0	7.0
86	52	8.8
97	86	25.0

Reference[2] reports that for mineral fibre insulation with densities 148 to 172 $kg \cdot m^{-3}$ the water vapour permeability is 1.27×10^{-10} $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1}$.

- **Air permeability[3]:**

Pressure Pa	**Permeability $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1} \times 10^{-5}$**
10	2.2
20	2.0
30	2.0
40	1.9
50	1.9
60	1.8
70	1.8
80	1.8
90	1.8

2.20 Expanded Polystyrene Insulation

- **SOURCES**

[1]Catalogue of Material properties(upgraded version), Report Annex XIV, Page 2.25

[2]Institute for Research in Construction, NRC, Canada, data, according to ASTM Standard C177.

[3]Laboratory of Building Physics, KU-Leuven, Belgium, data. according to Belgian standard B62-003.

[4]Kurt Kielsgaard Hansen, Sorption Isotherms, A Catalogue, The Technical University of Denmark, Technical Report 162/86; the data corresponds to a sample with the following specifications: density = 31 kg·m^{-3}; the data originally appeared in Tech. Report 36, Lund Inst. of Technology by Ahlgren Lennart, 1972.

[5]Institute for Research in Construction, NRC, Canada, data; density ≈ 11.5 kg·m^{-3}.

[6]Data from CMHC, Canada report on "Air permeance of building materials"; specimens were 1m x 1 m.

- **Dry density[1]** 11 to 40 kg·m^{-3}
- **Heat capacity[1]** 1470 J·K^{-1}·kg^{-1}

- **Thermal conductivity of the dry material as a function of density:**

Reference[1] gives the following equations at 10 and 20 °C:

$$\lambda\ (W\cdot m^{-1}\cdot K^{-1}) = 0.0174 + 1.9 \times 10^{-4}\rho + 0.258/\rho$$
$$\lambda\ (W\cdot m^{-1}\cdot K^{-1}) = 0.0213 + 1.2 \times 10^{-4}\rho + 0.235/\rho$$

- **Temperature dependence of thermal conductivity:**

Specimen 1[2]: Density =23.2 kg·m^{-3}, thickness = 79 mm

T,Hot surface °C	T, Cold surface °C	Temperature °C	λ W·m^{-1}·K^{-1}
13.09	-10.92	1.09	0.0324
22.23	-0.92	10.66	0.0336
30.14	7.28	18.71	0.0344
35.83	13.34	24.59	0.0352
47.28	25.58	36.43	0.0366
52.70	31.08	41.89	0.0371

Specimen 2[3]: Density = 25.5 kg·m^{-3}, thickness = 150.3 mm

T,Hot surface °C	T, Cold surface °C	Temperature °C	λ W·m^{-1}·K^{-1}
15.1	4.9	10.0	0.0333
24.9	14.8	19.9	0.0345
34.9	24.9	29.9	0.0357

- **Thermal conductivity of moist material:**

Reference[1] reports the following equations at 20 °C:

$\lambda(\psi) = 0.0390 + 0.00197\psi$ dry density 15 kg·m^{-3}
$\lambda(\psi) = 0.0348 + 0.00190\psi$ dry density 20 kg·m^{-3}
$\lambda(\psi) = 0.0326 + 0.00274\psi$ dry density 25 kg·m^{-3}
$\lambda(\psi) = 0.0331 + 0.00123\psi$ dry density 30 kg·m^{-3}

where : ψ is the moisture content expressed as m^3·m^{-3}

- **Sorption/desorption curve[4]:**

Relative humidity %	Sorption moisture content kg•kg^{-1}	Desorption moisture content kg•kg^{-1}
20.3	0.030	
42.9	0.041	
65.0	0.040	
85.3	0.040	
94.4	0.050	
97.9	0.050	
20.0		0.020
44.5		0.040
65.1		0.048
84.5		0.056
95.1		0.070
97.9		0.080

- **Water Vapour Permeability (from cup method)[5] at 23 °C:**

RH(1) %	RH(2) %	Water vapour permeability $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1}$ x 10^{-11}
0	28.7	1.1
0	50.9	0.85
22.7	50.8	0.86
43.2	61.5	0.72
50.9	69.1	0.95
61.5	81.2	1.1
61.4	100	1.1
80.4	100	1.1
92.4	100	1.2

Reference[1] gives the following equation for the dependence of water vapour permeability on dry density, for a mean RH 86 %:

$$\delta = 1/(2.6 \times 10^{10} + 1.04 \times 10^{10}\rho)$$

- **Air permeability[6]:**

Specimen 1: Density = 16 $kg \cdot m^{-3}$, thickness = 25.4 mm

Pressure difference Pa	Permeability $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1} x 10^{-6}$
25	5.6
50	5.2
75	5.0
100	4.9

Specimen 2: Density = 25 $kg \cdot m^{-3}$, thickness = 25.4 mm

Pressure difference Pa	Permeability $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1} x 10^{-8}$
25	4.9
50	4.9
75	4.9
100	4.9

2.21 Cellulose Insulation

- **SOURCES**

[1]Institute for Research in Construction, NRC, Canada, data.

[2]Catalogue of Material properties(upgraded version), Report Annex XIV, “newspaper”, Page 2.35

[3]Institute of Construction and Architecture of SAS, Department of Building Physics, Slovakia, data.

[4]Marchand, R. and M. K. Kumaran, Journal of Thermal Insulation and Building Envelopes, p 362-377, 1994.

[5]Data from CMHC Canada report on "Air permeance of building materials"; specimens were 1 m x 1 m and 38 mm thick; density not specified

- **Dry density[1]** 15 to 55 $kg{\cdot}m^{-3}$
- **Heat capacity[2]** 1880 $J{\cdot}K^{-1}{\cdot}kg^{-1}$
- **Thermal conductivity of the dry material at 24 °C as a function of density[1] according to ASTM Standard C518:**

Density $kg{\cdot}m^{-3}$	Thickness mm	λ $W{\cdot}m^{-1}{\cdot}K^{-1}$
16	152	0.0423
33	88	0.0381
45	152	0.0381
48	152	0.0391
52	152	0.0392

- **Thermal conductivity of moist material [3];**

moisture content $kg{\cdot}kg^{-1}$	T,Hot surface °C	T, Cold surface °C	λ $W{\cdot}m^{-1}{\cdot}K^{-1}$
0	25	20	0.038
0.12	25	20	0.043
0.24	25	20	0.057

- **Sorption curve[2]:**

Relative humidity %	Sorption moisture content kg•kg^{-1}
33	0.053
52	0.090
75	0.129
86	0.169
97	0.321
98	0.409

- **Sorption/desorption curve[3]:**

Relative humidity %	Sorption moisture content kg•kg^{-1}	Desorption moisture content kg•kg^{-1}
25	0.032	0.054
44	0.070	0.098
66	0.105	0.137
86	0.182	0.233

- **Water Vapour Permeability (from cup method)[1] at 23 °C:**

Density kg.m^{-3}	RH(1) %	RH(2) %	Water vapour permeability kg·m^{-1}·s^{-1}·Pa^{-1} x 10^{-10}
25.6	52.1	0.0	1.1
25.6	100	50.5	1.5
48.0	50.9	0.0	1.1
48.0	100	50.8	1.3

- **Moisture diffusivity**[4]:

Moisture content (kg·m^{-3})	Moisture diffusivity (m^2·s^{-1})
2	2.4E-09
5	4.1E-09
10	5.9E-09
20	8.2E-09
32	9.8E-09
40	1.1E-08
49	1.2E-08
58	1.2E-08
68	1.3E-08
79	1.3E-08

Moisture content ($kg{\cdot}m^{-3}$)	**Moisture diffusivity ($m^2{\cdot}s^{-1}$)**
88	1.2E-08
95	1.2E-08
102	1.1E-08
110	1.0E-08
119	8.6E-09
130	6.9E-09
137	5.9E-09
145	4.9E-09
155	3.8E-09
168	2.7E-09
189	1.0E-09

- **Air permeability[5]:**

Pressure difference Pa	**Permeability $kg{\cdot}m^{-1}{\cdot}s^{-1}{\cdot}Pa^{-1}x10^{-5}$**
25	5.5
50	5.3
75	5.3
100	5.2

2.22 Extruded Polystyrene Insulation

- **SOURCES**

[1]Catalogue of Material properties(upgraded version), Report Annex XIV, Page 2.25

[2]Institute for Research in Construction, NRC, Canada, data.

[3]Laboratory of Building Physics, KU-Leuven, Belgium data, according to Belgian standard B62-003.

[4]VTT, Finland data, density 30 kg·m^{-3}.

[5] Dipartimento di Energetica, Universita di Ancona, Italy, data;density of specimen 36.2 kg.m^{-3} and thickness 24.6 mm.

- **Dry density[1]** 25 to 55 kg·m^{-3}
- **Heat capacity[1]** 1470 J·K^{-1}·kg^{-1}
- **Thermal conductivity of the dry material as a function of density:**

Reference[1] gives the following equations at 10 and 20 °C:

$$\lambda\ (\mathrm{W{\cdot}m^{-1}{\cdot}K^{-1}}) = 0.0174 - 1.58\times10^{-5}\rho + 0.263/\rho$$
$$\lambda\ (\mathrm{W{\cdot}m^{-1}{\cdot}K^{-1}}) = 0.0404 - 3.87\times10^{-4}\rho + 0.029/\rho$$

- **Ageing curve or time dependence of thermal conductivity at 24 °C according to ASTM Standard C518:**

Specimen 1[2]: Density =25.0 kg·m^{-3}, thickness = 52.5 mm

age **day**	**λ** **W·m^{-1}·K^{-1}**
0	0.0263
57	0.0283
74	0.0286
102	0.0289
179	0.0293
561	0.0298
681	0.0301
800	0.0303
920	0.0307
1040	0.0305

Specimen 2[2]: Density =24.5 kg·m^{-3}, thickness = 50.5 mm

age , day	λ, W·m^{-1}·K^{-1}
0	0.0219
45	0.0256
60	0.0261
91	0.0266
182	0.0273
270	0.0275
365	0.0274
451	0.0277
550	0.0279
673	0.0280
791	0.0280
911	0.0287
1031	0.0285

Specimen 3[2]: Density =25.0 kg·m^{-3}, thickness = 52.3 mm

age, day	λ, W·m^{-1}·K^{-1}
0	0.0261
567	0.0298
687	0.0301
806	0.0301
926	0.0308
1050	0.0306

Specimen 4[2]: Density =28.6 kg·m^{-3}, thickness = 50.1 mm

age, day	λ, W·m^{-1}·K^{-1}
0	0.0220
55	0.0264
71	0.0268
99	0.0273
179	0.0280
270	0.0285
361	0.0283
452	0.0285
554	0.0286
677	0.0288
797	0.0288
994	0.0294

- **Temperature dependence of thermal conductivity:**

Specimen 1[3]: Density =30.7 kg·m^{-3}, thickness = 19.4 mm

T,Hot surface °C	**T, Cold surface °C**	**Temperature °C**	**λ W·m^{-1}·K^{-1}**
4.7	-4.8	-0.05	0.0266
14.6	5.6	10.1	0.0278
24.5	15.7	20.1	0.0292
34.4	25.6	30.0	0.0303

Specimen 2[3]: Density =30.6 kg·m^{-3}, thickness = 19.6 mm

T,Hot surface °C	**T, Cold surface °C**	**Temperature °C**	**λ W·m^{-1}·K^{-1}**
5.1	-4.4	0.35	0.0264
14.9	6.0	10.45	0.0279
24.8	16.1	20.45	0.0297
34.6	26.0	30.3	0.0305

Specimen 3[3]: Density = 38.45 kg·m^{-3}, thickness = 27.64 mm

T,Hot surface °C	**T, Cold surface °C**	**Temperature °C**	**λ W·m^{-1}·K^{-1}**
5.0	-5.0	0	0.0215
15.0	5.0	10.0	0.0215
20.0	0.0	10.0	0.0220
25.0	15.0	20.0	0.0225
35.0	25.0	30.0	0.0235

- **Thermal conductivity of moist material:**

Reference [1] reports the following equations at 10 and 20 °C for a sample of density 35 kg·m^{-3}:

$$\lambda(\psi) = 0.0240 + 1.6 \times 10^{-4}\psi + 5.8 \times 10^{-5}\psi^2$$
$$\lambda(\psi) = 0.0251 + 5.2 \times 10^{-5}\psi + 7.0 \times 10^{-5}\psi^2$$

where ψ is the moisture content expressed as m^3·m^{-3}

- **Sorption/desorption curve[2]:**

Relative humidity **%**	**Sorption moisture content** **$kg \cdot kg^{-1}$**
25	0.0007
50	0.0006
75	0.0013
90	0.0017

- **Water Vapour Permeability (from cup method):**

RH(1) **%**	**RH(2)** **%**	**RH** **%**	**Water vapour permeability** **$kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1}$ x 10^{-12}**
0	52		1.7[2]
3	50		2.1[5]
		86	1.2 [1]
		25	0.95[4]
		50	1.0[4]
		75	1.2[4]
		95	1.35[4]

Reference[1] gives the following equation for the dependence of water vapour permeability on dry density, for a mean RH 86 %:

$$\delta = 1/(2.55 \times 10^{11} + 1.76 \times 10^{10}\rho)$$

- **Air permeability[3]:**
  Density = 30.7 $kg \cdot m^{-3}$, thickness = 20 mm

Pressure difference **Pa**	**Permeability** **$kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1} x10^{-9}$**
75	9.6
150	9.3
225	9.2

2.23 Polyurethane Foam Insulation

- SOURCES

[1]Catalogue of Material properties(upgraded version), Report Annex XIV, Page 2.27

[2]Institute for Research in Construction, NRC, Canada, data.

[3]Kumaran, M.K. et al. J.Thermal Insulation, 1989, p.123-137.

[4]Bomberg, M.T. et al. J.Thermal Insulation, 1991, p. 241-267.

[5]Laboratory of Building Physics, KU-Leuven, Belgium, data at 26.1 °C; density 28.7 $kg{\cdot}m^{-3}$.

[6]Laboratory of Building Physics, KU-Leuven, Belgium, data at 35.8 °C; density 28.7 $kg{\cdot}m^{-3}$.

[7]VTT, Finland, data; density 40 $kg{\cdot}m^{-3}$.

- **Dry density[1,2]** 20 to 55 $kg.m^{-3}$

- **Heat capacity[1]** 1470 $J{\cdot}K^{-1}{\cdot}kg^{-1}$

- **Thermal conductivity of the dry material as a function of density:**

Reference[1] gives the following equations at 10 and 20 °C:

$$\lambda\ (W{\cdot}m^{-1}{\cdot}K^{-1}) = -0.1119 + 1.86\times10^{-3}\rho + 2.362/\rho$$
$$\lambda\ (W.m^{-1}.K^{-1}) = -0.0083 + 5.11\times10^{-4}\rho + 0.436/\rho$$

- **Ageing curve or time dependence of thermal conductivity at 24 °C according to ASTM Standard C518:**

Specimen 1[2]: Density =32.7 $kg{\cdot}m^{-3}$, thickness = 38 mm

age, day	λ, $W{\cdot}m^{-1}{\cdot}K^{-1}$
0	0.0175
32	0.0188
61	0.0198
90	0.0208
185	0.0219
270	0.0227
360	0.0231
451	0.0236
567	0.0241
690	0.0243
810	0.0249
932	0.0247

Specimen 2[2]: Density =55.3 kg·m^{-3}, thickness = 51 mm

age, day	λ, W·m^{-1}·K^{-1}
0	0.0198
31	0.0205
64	0.0208
92	0.0212
179	0.0220
270	0.0230
374	0.0237
497	0.0244
617	0.0249
737	0.0259
858	0.0261

- **Temperature dependence of thermal conductivity:**

Note:The blowing agents used in polyurethane foam insulations (CFCs and HCFCs) can undergo condensation within the closed cells. This process has significant influence on the temperature dependence of the thermal conductivity. In the temperature range of -20 to +30 °C, λ plotted against temperature gives a "V" shaped curve; the minimum point depends on the age of the foam and the nature of the blowing agent. Further details on this can be obtained from References [4,5]

- **Water Vapour Permeability (from cup method):**

RH(1) %	RH(2) %	RH %	Water vapour permeability kg·m^{-1}·s^{-1}·Pa^{-1} x 10^{-12}
0	50		2.9[2]
		86	8.3 [1]
0.8	52.5		3.8[5]
75	91.8		4.0[5]
92.1	97.0		9.1[5]
1	49.4		4.9[6]
75	88.9		5.2[6]
89.2	96.9		11.8[6]
		25	2.1[7]
		50	2.15[7]
		75	2.2[7]
		95	2.3[7]

Reference[1] gives the following equation for the dependence of water vapour permeability on dry density, for a mean RH of 86 %:

$$\delta = 1.14\text{x}10^{-10} / \exp(0.088\rho)$$

2.24 Polyisocyanurate Foam Insulation

- SOURCES

[1]Catalogue of Material properties(upgraded version), Report Annex XIV, Page 2.27

[2]Institute for Research in Construction, NRC, Canada, data.

- **Dry density[1,2]** 20 to 55 $kg{\cdot}m^{-3}$
- **Heat capacity[1]** 1470 $J{\cdot}K^{-1}{\cdot}kg^{-1}$
- **Thermal conductivity of the dry material as a function of density:**

Reference[1] gives the following equations at 10 and 20 °C:

$$\lambda\ (W{\cdot}m^{-1}{\cdot}K^{-1}) = -0.1119 + 1.86\times10^{-3}\rho + 2.362/\rho$$
$$\lambda\ (W{\cdot}m^{-1}{\cdot}K^{-1}) = -0.0083 + 5.11\times10^{-4}\rho + 0.436/\rho$$

- **Ageing curve or time dependence of thermal conductivity at 24 °C according to ASTM Standard C518:**

Specimen 1[2]: Density =39.6 $kg{\cdot}m^{-3}$, thickness = 52 mm

age, day	λ, $W{\cdot}m^{-1}{\cdot}K^{-1}$
30	0.0183
60	0.0189
90	0.0193
118	0.0197
209	0.0211
300	0.0214
391	0.0219
482	0.0223
600	0.0229
720	0.0233
842	0.0235
963	0.0236

Specimen 2[2]: Density =39.8 kg·m^{-3}, thickness = 52 mm.

age, day	λ, W·m^{-1}·K^{-1}
0	0.0183
821	0.0220
940	0.0226
1058	0.0228
1180	0.0236
1300	0.0234

- **Sorption/desorption curve[2]:**

Relative humidity %	Sorption moisture content kg•kg^{-1}
25	0.002
50	0.003
75	0.006
90	0.007

- **Water Vapour Permeability (from cup method):**

RH(1) %	RH(2) %	RH %	Water vapour permeability kg·m^{-1}·s^{-1}·Pa^{-1} x 10^{-12}
0	52		2.2[2]
		86	8.3 [1]

Reference[1] gives the following equation for the dependence of water vapour permeability on dry density, for a mean RH of 86 %:

$\delta = 1.14\mathrm{x}10^{-10} / \exp(0.088\rho)$

2.25 Phenolic Foam Insulation

- SOURCE

[1] Institute for Research in Construction, NRC, Canada, data.

- **Dry density[1]** 30 to 60 kg·m^{-3}

- **Ageing curve or time dependence of thermal conductivity at 24 °C according to ASTM Standard C518:**

Specimen 1[1]: 52 mm thick boards with facers; bulk density 65 kg·m^{-3}

age, day	λ, W·m^{-1}·K^{-1}
0	0.0174
20	0.0173
36	0.0173
64	0.0173
96	0.0175
180	0.0176
268	0.0179
365	0.0175
450	0.0177
544	0.0177

Specimen 2[1]: 63 mm thick boards with facers; bulk density 65 kg·m^{-3}

age, day	λ, W·m^{-1}·K^{-1}
18	0.0184
51	0.0185
91	0.0185
179	0.0186
269	0.0186
360	0.0188
464	0.0187
585	0.0188
704	0.0190
827	0.0192
948	0.0191

- **Sorption curve[1]:**

Relative humidity %	Sorption moisture content $kg \bullet kg^{-1}$
25	0.012
50	0.018
75	0.026
90	0.030

- **Water Vapour Permeability (from cup method):**

RH(1) %	RH(2) %	Water vapour permeability $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1} \times 10^{-13}$
0	52	7.8[1]

2.26 Perlite Board

- SOURCE

[1] Laboratory of Building Physics, KU-Leuven, Belgium, data.

- **Dry density[1]** 160 kg·m^{-3}

- **Temperature dependence of thermal conductivity[1]:**

Temperature °C	λ W·m^{-1}·K^{-1}
1.6	0.0515
11.5	0.0525
21.4	0.054
31.4	0.055

- **Sorption curve[1]:**

Relative humidity %	Sorption moisture content kg•kg^{-1}
33	1.3
52	1.6
75	2.6
86	3.8
97	8.0
99.8	11.7

- **Water Vapour Permeability (from cup method)[1]:**

RH(1) %	RH(2) %	Water vapour permeability kg·m^{-1}·s^{-1}·Pa^{-1} x 10 $^{-11}$
0.0	52	2.8
52	86	3.3
86	97	8.2

- **Air permeability[1]:**

Pressure Pa	**Permeability $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1} x10^{-7}$**
10	2.6
20	2.5
30	2.4
40	2.4
50	2.3
60	2.3
70	2.3
80	2.3
90	2.3

2.27 Feathers Of Chicken

- **SOURCE**

[1] Laboratory of Building Physics, KU-Leuven, Belgium, data.

- **Dry density[1]** 70 to 85 kg·m^{-3}

- **Temperature dependence of thermal conductivity[1]:**

Temperature °C	λ W·m^{-1}·K^{-1}
10.1	0.0380
30.0	0.0410
10.1*	0.0511
20.0*	0.0557
30.1*	0.0638

* moist material with 0.13 kg•kg^{-1} moisture content

- **Sorption curve[1]:**

Relative humidity %	Sorption moisture content kg•kg^{-1}
52	0.046
75	0.077
86	0.083
97	0.125

2.28 Finishing Materials[1]

2.28.1 Wall paper

Wallpaper	Type	mass(kg/m²)	d(mm)
1	textile	0.291	0.425
2	vinyl	0.216	0.325
3	textile	0.333	0.700
4	vinyl	0.212	0.450
5	paper	0.168	0.280
6	paper	0.151	0.280

2.28.1.1 Moisture Content (%Kg•Kg^{-1} (U), φ In %)

- Suction Curve

Sorption:

φ (%)	u (%kg•kg^{-1})					
paper:	**1**	**2**	**3**	**4**	**5**	**6**
33	3.2	1.4	2.9	1.2	1.6	1.8
52	5.5	2.8	5.5	2.3	2.9	4.0
75	7.9	5.0	6.4	3.3	4.6	5.5
86	11.2	8.2	9.8	4.8	7.2	6.8
97	21.4	40.0	24.9	13.3	15.8	16.9

desorption:

φ (%)	u (%kg•kg^{-1})					
paper:	**1**	**2**	**3**	**4**	**5**	**6**
33	5.3	4.6	4.0	7.0	2.7	3.9
52	8.5	5.6	6.6	8.3	4.2	6.0
75	11.8	8.7	9.9	9.8	6.9	9.4
86	16.1	10.7	14.0	10.0	9.7	12.3
97	42.8	52.2	38.3	17.9	23.8	36.2

2.28.1.2 Diffusion Thickness:

φ (%)	µd (m)					
paper:	**1**	**2**	**3**	**4**	**5**	**6**
33-52	0.280	2.140	0.155	0.090	0.035	0.025
52-98	0.006	0.180	0.019	0.025	0.012	0.008

---

[1] From Catalogue of Material Properties (upgraded version), Report Annex XIV.

2.28.2 Wall Paint

2.28.2.1 Diffusion Thickness:

paint	μd (m)		
	φ (%)≈ 42.5	φ (%)≈ 75.4	φ (%)≈ 86.0
PAINT ON GYPSUM			
primer + 2*latex 1			0.17
primer + 2*latex 2	4.50		1.10
primer + 2*acryl			0.46
primer + 2*synthetic	3.20		1.00
primer + 2*oil			0.76
PAINT ON CELLULAR CONCRETE			
primer + 2*acryl (weathered)		0.43	
structured paint (d = 1.5mm)		1.10	

2.28.3 Carpet

Mass per area : 2.18 $kg \cdot m^{-2}$

2.28.3.1 Moisture Content: (%$Kg \cdot Kg^{-1}$ (U), $0 < \varphi \le 1$)

- Suction curve (%$kg \cdot kg^{-1}$) :

  sorption : $50 .[1 - \ln \varphi / 8.27.10^{-3}]^{-1/2.70}$

  $r^2 = 0.99$

  $\varphi / (-0.202. \phi^2 + 0.255. \varphi - 0.022)$

  $r^2 = 0.96; 0.40 < \varphi \le 0.98$

φ (%)	u(%$kg \cdot kg^{-1}$)
33	8.0
52	9.9
75	13.4
86	17.2
97	29.7
98	29.8

2.28.4 Timber Slabs

Mass Per Area : 4.00 $kg \cdot m^{-2}$ (d = 0.01m)

2.28.4.1 Moisture Content: (%Kg•Kg^{-1} (U), $0 < \varphi \leq 1$)

- suction curve (%kg•kg^{-1}) :

sorption : $50 \,.[1 - \ln\varphi /0.0213]^{-1/1.96}$
$r^2 = 0.98$
$\varphi / (-0.145 \;\; \varphi^2 + 0.154. \, \varphi + 0.019)$
$r^2 = 0.91$

desorption : $50 \,.[1 - \ln\varphi /0.0379]^{-1/1.86}$
$r^2 = 0.96$
$\varphi / (-0.152. \, \varphi^2 + 0.168. \, \varphi + 0.0045)$
$r^2 = 0.70$

	sorption	**desorption**
φ (%)	**u(%kg•kg^{-1})**	
33	5.8	7.1
52	9.4	12.3
75	13.7	15.4
86	17.6	20.8
97	31.4	37.3
98	34.5	

2.28.4.2 Diffusion Thickness

: 0.86 m (mean value)
σ = 0.12 m; 5 samples
φ = 55 %

2.28.5 Foils/ Vapour Barriers

2.28.5.1 Vapour Resist. Factors:

d(mm)		**μ(-.10³)**				
vapour barrier		**φ (%)≈28**	**φ (%)≈52**	**φ (%)≈70**	**φ (%)≈75.4**	**φ (%)≈86**
PE-foil	0.1 to 0.2		321		289	271

2.28.5.2 Diffusion Thickness:

upper number = lowest value measured
lower number = highest value measured

	d(mm)	**µd(m)**			
vapour barrier		φ (%)≈52	φ (%)≈70	φ (%)≈75.4	φ (%)≈86
bituminous paper	0.1				1.80
					2.80
bituminous paper	0.2	0.70			
bituminous paper	1.4			1.70	
				6.90	
bituminous paper	0.4		3.90		
			8.10		
aluminium-paper	0.1				2.00
					2.80
aluminium paper	0.2				0.17
					0.33
aluminium paper	0.24			17.80	
				77.30	
aluminium paper	-				6.80
					17.80
glass fabric reinf.	0.4			3.80	
aluminium paper				4.70	
glass fabric reinf.	0.4				12.00
PVC-foil					29.00
PE-foil, stapled	0.15			7.70	

Appendices

APPENDIX I

REPORT ON MEASUREMENTS TO DETERMINE MOISTURE DIFFUSIVITY OF EASTERN WHITE PINE

BACKGROUND:

Moisture diffusivity, D_W, is one of the moisture transport properties of building materials frequently used in hygrothermal analysis. It appears in the moisture transport equation:

$$\dot{\mathbf{m}}_m = -\rho_0 \mathbf{D}_w \mathbf{grad} \;\; \mathbf{u} \qquad [1]$$

At the first meeting of the Annex it was noted that each participating country has its own experimental and analytical procedures to determine this transport property. It was also noted that the value of this property as reported in literature for a given material at times differed by one or two orders of magnitude. Hence it was decided to organize a common exercise as follows:

"Canada will provide the participants with a test specimen of eastern white pine cut from a carefully selected sample of the material and each participant will determine the moisture diffusivity according to the procedures developed by the participant."

Moisture transport in the longitudinal direction was chosen for the investigation. The bulk dry density of the sample was ≈ 367 $kg{\cdot}m^{-3}$. Belgium, Germany, Finland and Canada participated in the exercise. This report summarizes the results from the common exercise. The results are compared in Figure 1.

METHOD AND RESULTS FROM BELGIUM

A horizontal moisture infiltration process was investigated. The size of the test specimen was 202.77 mm x 135. 05 mm x 40.94 mm . The initial moisture content was 0.076 $kg{\cdot}kg^{-1}$. The transient moisture distribution in the specimen at 151 locations, 0.5 mm apart, was determined at selected intervals for 34 days. Gamma ray attenuation method was used to measure the moisture content.

The experimental results were analyzed using two different methods:

Boltzmann transformation method and
Flow/Gradient Method

Further details on the experimental technique and data analysis are given in References 1 and 2.

METHOD AND RESULTS FROM GERMANY

A horizontal moisture infiltration process was investigated. The size of the test specimen was 150 mm x 20 mm x 20 mm . The initial moisture content corresponded to 65 % RH at 20 °C. The transient moisture distribution in the specimen was determined at selected intervals for 280 h. A Nuclear Magnetic Resonance method was used to measure the moisture content. Measurements were done on a sealed specimen and an unsealed specimen. The experimental results were analyzed using a flow/gradient method. A set of time dependent moisture diffusivity derived using the measurements on the sealed specimen were reported. Further details on the experimental technique and data analysis are given in Reference 3.

METHOD AND RESULTS FROM FINLAND

A vertical moisture intake process was investigated. The size of the test specimen was ≈300 mm x 50 mm x 50 mm . The transient moisture distribution in the specimen was determined at selected intervals for 45 days. Gamma ray attenuation method was used to measure the moisture content. Measurements were done on three separate specimens. The experimental results were analyzed using the Boltzmann transformation method. Further details on the experimental technique and data analysis are given in References 4 and 5.

METHOD AND RESULTS FROM CANADA

A vertical moisture intake process was investigated. The size of the test specimen was ≈327 mm x 52 mm x 52 mm . The initial moisture content was 0.076 $kg{\cdot}kg^{-1}$. The transient moisture distribution in the specimen at 66 locations, 2 mm apart, was determined at selected intervals for 45 days. Gamma ray attenuation method was used to measure the moisture content. Measurements were done on three separate specimens.

The experimental results were analyzed using an optimization technique. Further details on the experimental technique and data analysis are given in References 6 to 8.

DISCUSSION

It is quite clear from the results of this exercise that the property called moisture diffusivity for a building material is not a unique property, as determined by any currently available technique. Measurements done in Canada on three specimens cut side by side from the material gave different values. The results from Finland on three separate specimens agreed reasonably well to one another, yet were different from the results reported from Canada. The upper and lower values from Canada, one value from Finland, the value from Belgium calculated according to Boltzmann Transformation method and the results from the final value reported by Germany are compared in Figure 1. One may immediately ask, "What is the moisture diffusivity for eastern white pine?" It is true that this common exercise has not resulted in a unique set of values for this property as a function of moisture content. But it appears that it has confirmed the order of magnitude of the property. For a good range of moisture content this is $\approx 10^{-10}\ m^2{\cdot}s^{-1}$.

The results from Germany and the results from Belgium using the Flow/Gradient method give a range of values for moisture diffusivity. It depends on the time of the measurement. If this is the case, the whole concept of using moisture diffusivity and equation (1) for hygrothermal analysis is questionable. On the other hand, is it appropriate to use the Flow/Gradient method to analyze transient moisture distribution? This approach has to be critically reviewed. In the Flow/Gradient method in addition to the moisture distribution one has to either measure or estimate the flow at each location. How well can we do this ?

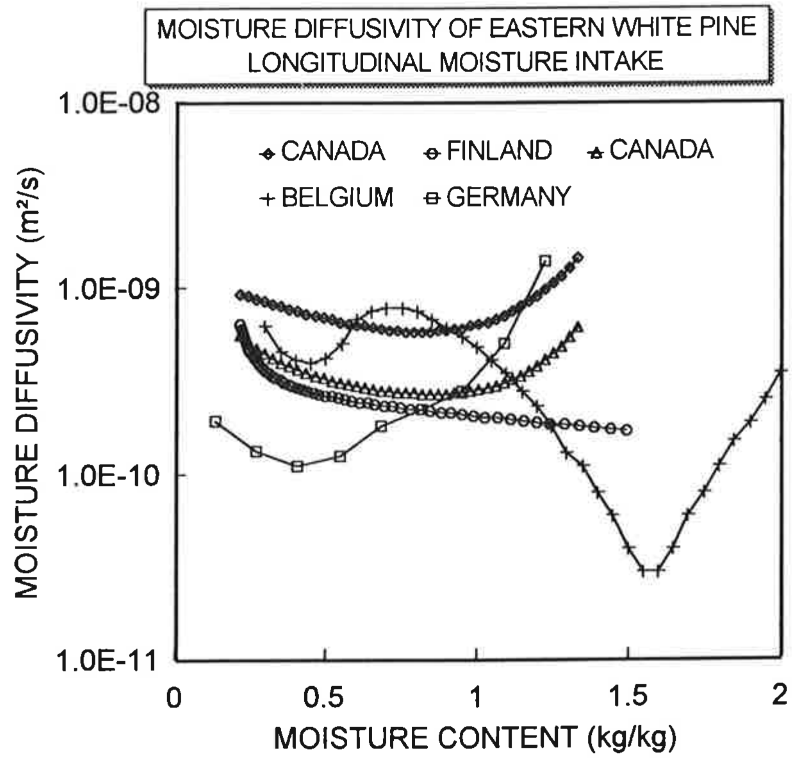

Figure 1. Comparison of the moisture diffusivities determined by four participating countries for one sample of eastern white pine.

The other two methods for the analysis, namely the Boltzmann transformation and optimization technique also have limitations. If the data from a series of measurements, when subjected to Boltzmann transformation, fall on a characteristic curve the indication is that there is a property called moisture diffusivity, as defined by equation (1). For the sample of pine used for the present investigation this appears to be the case. However, there are some problems with the data from Canada and Finland to define the beginning and the end of the characteristic curve exactly. This can introduce large uncertainty in the moisture diffusivity derived at the lower moisture content range.

The optimization technique directly uses the measured quantities, namely time, position and moisture content from the entire series of measurements and solves the balance equation that corresponds to equation [1]. The objective is to derive moisture diffusivity, the only unknown quantity in the balance equation, as a function of the moisture content for the full range that is measured and to reproduce all the measured quantities as best as possible. In principle this is all right, if one accepts equation (1). But is it possible to derive a unique functional dependence on moisture content ? This question has to be answered convincingly.

REFERENCES

1. Descamps F. Moisture content measurement using gamma ray attenuation, Research Report, Laboratory for Building Physics, K U Leuven, 1990.

2. Descamps F. Measurement and calculation of the wetting water diffusivity of eastern white pine, Annex XXIV paper T3-B-91/03, 1991.

3. Krus M. and Kieβl K. NMR-measurement of capillary penetration behaviour of water and hydrophobic agent in porous stone and derivation of new capillary transport values, Research report, Fraunhofer-Institute of Building Physics, FtB-12e, 1991.

4. Kohonen R. A method to analyze the transient hygrothermal behaviour of building materials and components, Technical Research Centre of Finland Publications 21, 1984.

5. Saarimaa J., Nieminen J., Rautiainen L., Ojanen T. and Kohonen R. Moisture transfer in building structures: hygrothermal properties of building materials, VTT Research Reports 644, 1989.

6. Kumaran, M.K. and Bomberg M.T. A Gamma-Ray Spectrometer for Determination of Density Distribution and Moisture Distribution in Building Materials, Proceedings of the International Symposium on Moisture and Humidity, 1985, pp. 485-490.

7. Kumaran M.K., Mitalas G.P., Ojanen T. and Kohonen R. Moisture Transport Coefficient of Pine form Gamma Ray Absorption Measurements , ASME Paper, HTD-Vol. 123, 1989, pp. 179-183.

8. Salonvaara M. A Transient Method to Determine Moisture and Heat Transport Coefficients of Porous Materials", Proceedings of the 2nd Symposium on Building Physics in the Nordic Countries, Trondheim, Norway, 1990, pp.355-360.

APPENDIX II

REPORT ON ANALYTICAL METHODS TO DERIVE MOISTURE DIFFUSIVITY FROM TRANSIENT MOISTURE DISTRIBUTION

BACKGROUND:

As a part of the Annex activities, several common exercises were planned. Belgium, Germany, Finland and Canada participated in an earlier common exercise to compare some of the experimental procedures to determine the moisture diffusivity of building materials(Appendix I). As a result, it was noted that three different analytical procedures are used to derive moisture diffusivity using experimental results on transient moisture distribution during a moisture infiltration process. Hence a follow up exercise was planned as follows:

"Canada will provide experimental data on transient moisture distribution in a test specimen of spruce to all participants and each participant will analyze the data to derive moisture diffusivity using the method developed by the participant"

Canada provided the information given in Appendix A to Belgium, Germany and Finland. Each participant analyzed the data and derived the values for moisture diffusivity. This report summarizes the results from the common exercise.

RESULTS FROM BELGIUM

The information provided was insufficient to use the Flow/Gradient method. The scatter in the data was too much to apply the Boltzmann transformation method either. Hence Belgium reported the results as follows:

> "Our last resort is to fit a parametric diffusivity function to the measurement data. It was found that a constant diffusivity or a straight line diffusivity give a good fit in the measured moisture content range (up to u_{MAX} = 198 % kg/kg)." The results presented by Belgium are shown in Figure 1.

RESULTS FROM GERMANY

The method of calculation was not reported. But it appears that the experimental data at each interval were smoothened prior to analysis and a Flow/Gradient method was used[1]. The results were reported as six sets, one time dependent set of values for each set of measurements. The final set is shown in Figure 1.

RESULTS FROM FINLAND

Finland used a Boltzmann transformation method[2,3]. Problem related to locating the value for the Boltzmann variable that corresponds to zero moisture content was reported.

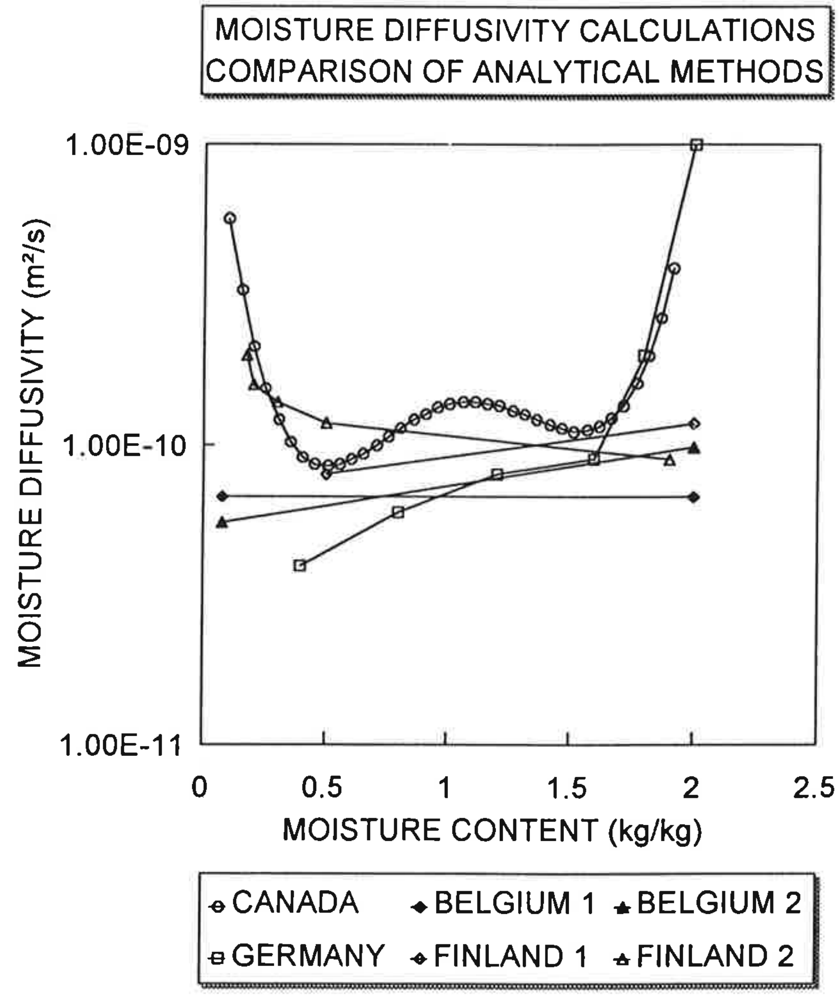

Figure 1. Comparison of the moisture diffusivities derived by four different participating countries, using various analytical methods but one set of moisture distribution data.

The accuracy of gamma radiation measurement in the low moisture content region was not particularly good. The results were analyzed using four different values for the Boltzmann variable at zero moisture content. The main difference between the four cases calculated by Finland is in the low moisture content range. Between 0.5 and 2 kg/kg the difference is not significant . One set of values is shown in Figure 1.

RESULTS FROM CANADA

The moisture diffusivity was analyzed using an optimization technique[4]. The moisture content data listed in Table 1 were used for the analysis. The optimized value for the moisture diffusivity is shown in Figure 1.

DISCUSSION

The values for moisture diffusivity derived by the four participating countries using the same set of experimental data on transient moisture distribution are compared in Figure 1. It is obvious that the shape of moisture diffusivity against moisture content curve depends on the analytical method used. However, all results in the moisture content range 0.5 to 2 kg/kg are within ± 30 % . Probably this difference of 30 % is not important in hygrothermal analysis as all the derived values seem to represent the moisture intake process reasonably well. The highest value obtained by the optimization technique very well reproduced the transient moisture distribution. The constant and linear moisture diffusivities derived by Belgium, though consistently lower than the value derived by Canada, also approximated the relation between the Boltzmann variable and the moisture content, to an acceptable level. So did all the four sets of values reported by Finland and the time dependent values reported by Germany. The various shapes seen Figure 1 may be just "art effects" of the analytical procedures used!

Table 1. The transient moisture distribution (g.cm^{-3}) data from Appendix A chosen for analysis using the optimization method; the six columns correspond to the six time intervals in Appendix 1 and the distance that corresponds to successive values in a column is 2 mm.

Time from the beginning of the process					
170 h	**314 h**	**650 h**	**890 h**	**1034 h**	**1346 h**
0.021	0.019	0.048	0.041	0.04	0.06
0.012	0.019	0.035	0.031	0.047	0.059
0.028	0.035	0.048	0.045	0.064	0.073
0.039	0.035	0.054	0.053	0.063	0.091
0.029	0.026	0.053	0.041	0.067	0.101
0.03	0.04	0.059	0.059	0.088	0.13
0.021	0.044	0.048	0.07	0.1	0.148
0.045	0.04	0.074	0.089	0.134	0.189
0.042	0.049	0.084	0.124	0.158	0.231
0.031	0.046	0.093	0.139	0.19	0.273
0.045	0.06	0.118	0.187	0.234	0.329
0.057	0.064	0.163	0.234	0.291	0.374
0.064	0.09	0.184	0.274	0.331	0.429
0.063	0.086	0.219	0.307	0.361	0.451
0.072	0.113	0.261	0.348	0.4	0.505
0.087	0.134	0.298	0.394	0.436	0.56
0.106	0.167	0.338	0.42	0.485	0.604
0.126	0.194	0.383	0.462	0.526	0.645
0.166	0.252	0.439	0.519	0.592	0.72
0.177	0.282	0.473	0.567	0.645	0.741
0.245	0.334	0.547	0.632	0.7	0.765
0.287	0.391	0.61	0.706	0.755	0.785

APPENDIX A. Information passed on to IEA participants for a common exercise.

Experimental data on a specimen of spruce for comparing the methods for data analysis to derive values for moisture diffusivity, in Annex XXIV activities. The density of the spruce is 396 $kg.m^{-3}$

The following table lists height, h, from the water/wood interface, time, t, and moisture concentration,w.

h / cm	t / h	w ($g \cdot cm^{-3}$)
8.15	168.51	0.016
7.95	168.57	0.003
7.75	168.60	0.011
7.55	168.64	0.011
7.35	168.68	0.020
7.15	168.72	0.018
6.95	168.76	0.018
6.75	168.80	0.019
6.55	168.85	0.021
6.35	168.89	0.021
6.15	168.93	0.016
5.95	168.97	0.013
5.75	169.01	0.016
5.55	169.05	0.007
5.35	169.09	0.021
5.15	169.13	0.012
4.95	169.18	0.028
4.75	169.22	0.039
4.55	169.26	0.029
4.35	169.30	0.030
4.15	169.34	0.021
3.95	169.38	0.045
3.75	169.42	0.042
3.55	169.47	0.031
3.35	169.51	0.045
3.15	169.55	0.057
2.95	169.59	0.064
2.75	169.63	0.063
2.55	169.67	0.072
2.35	169.71	0.087
2.15	169.75	0.106
1.95	169.80	0.127
1.75	169.84	0.168

h / cm	t / h	w (g·cm^{-3})
1.55	169.88	0.177
1.35	169.92	0.245
1.15	169.96	0.287
8.15	312.51	0.016
7.95	312.56	0.008
7.75	312.60	0.019
7.55	312.64	0.029
7.35	312.68	0.030
7.15	312.72	0.021
6.95	312.76	0.015
6.75	312.80	0.018
6.55	312.84	0.020
6.35	312.89	0.027
6.15	312.98	0.033
5.95	312.97	0.026
5.75	313.01	0.025
5.55	313.05	0.025
5.35	313.09	0.019
5.15	313.13	0.019
4.95	313.18	0.035
4.75	313.22	0.035
4.55	313.26	0.026
4.35	313.30	0.040
4.15	313.34	0.044
3.95	313.38	0.040
3.75	313.42	0.049
3.55	313.47	0.046
3.35	313.51	0.060
3.15	313.55	0.064
2.95	313.59	0.090
2.75	313.63	0.086
2.55	313.67	0.113
2.35	313.71	0.134
2.15	313.75	0.167
1.95	313.80	0.194
1.75	313.84	0.252
1.55	313.88	0.282
1.35	313.92	0.334
1.15	313.96	0.391
8.15	648.51	0.036
7.95	648.56	0.020
7.75	648.60	0.032
7.55	648.64	0.040
7.35	648.68	0.045
7.15	648.72	0.036

h / cm	t / h	w (g·cm^{-3})
6.95	648.76	0.036
6.75	648.80	0.034
6.55	648.84	0.031
6.35	648.89	0.041
6.15	648.93	0.035
5.95	648.97	0.047
5.75	649.01	0.041
5.55	649.05	0.044
5.35	649.09	0.048
5.15	649.13	0.035
4.95	649.16	0.048
4.75	649.22	0.053
4.55	649.26	0.053
4.35	649.30	0.059
4.15	649.34	0.048
3.95	649.38	0.074
3.75	649.42	0.084
3.55	649.46	0.093
3.35	649.51	0.118
3.15	649.55	0.163
2.95	649.59	0.184
2.75	649.63	0.219
2.55	649.67	0.261
2.35	649.71	0.298
2.15	649.75	0.338
1.95	649.79	0.383
1.75	649.83	0.439
1.55	649.86	0.473
1.35	649.92	0.547
1.15	649.96	0.610
8.15	888.51	0.034
7.95	888.56	0.016
7.75	888.60	0.033
7.55	888.64	0.035
7.35	888.68	0.037
7.15	888.72	0.029
6.95	888.76	0.024
6.75	888.80	0.031
6.55	888.84	0.024
6.35	888.89	0.040
6.15	888.93	0.037
5.95	888.97	0.039
5.75	889.01	0.038
5.55	889.05	0.029
5.35	889.09	0.041

h / cm	**t / h**	**w (g·cm^{-3})**
5.15	889.13	0.031
4.95	889.18	0.045
4.75	889.22	0.053
4.55	889.26	0.041
4.35	889.30	0.059
4.15	889.34	0.070
3.95	889.38	0.089
3.75	889.42	0.124
3.55	889.46	0.139
3.35	889.51	0.187
3.15	889.55	0.234
2.95	889.59	0.274
2.75	889.63	0.307
2.55	889.67	0.348
2.35	889.71	0.394
2.15	889.75	0.420
1.95	889.79	0.462
1.75	889.83	0.519
1.55	889.88	0.567
1.35	889.92	0.632
1.15	889.96	0.706
8.15	1032.5	0.029
7.95	1032.56	0.024
7.75	1032.60	0.030
7.55	1032.64	0.040
7.35	1032.68	0.045
7.15	1032.72	0.044
6.95	1032.76	0.043
6.75	1032.80	0.037
6.55	1032.84	0.047
6.35	1032.89	0.040
6.15	1032.93	0.036
5.95	1032.97	0.049
5.75	1033.01	0.046
5.55	1033.05	0.041
5.35	1033.09	0.040
5.15	1033.13	0.047
4.95	1033.18	0.064
4.75	1033.22	0.063
4.55	1033.26	0.067
4.35	1033.30	0.088
4.15	1033.34	0.100
3.95	1033.38	0.134
3.75	1033.42	0.158
3.55	1033.46	0.190

h / cm	t / h	w (g·cm^{-3})
3.35	1033.51	0.234
3.15	1033.55	0.291
2.95	1033.59	0.331
2.75	1033.63	0.361
2.55	1033.67	0.400
2.35	1033.71	0.436
2.15	1033.75	0.485
1.95	1033.79	0.526
1.75	1033.83	0.592
1.55	1033.88	0.645
1.35	1033.92	0.700
1.15	1033.96	0.755
8.15	1345.01	0.041
7.95	1345.06	0.030
7.75	1345.10	0.035
7.55	1345.14	0.045
7.35	1345.18	0.045
7.15	1345.22	0.042
6.95	1345.26	0.041
6.75	1345.30	0.038
6.55	1345.35	0.040
6.35	1345.39	0.046
6.15	1345.43	0.039
5.95	1345.47	0.058
5.75	1345.51	0.048
5.55	1345.55	0.046
5.35	1345.59	0.060
5.15	1345.63	0.059
4.95	1345.68	0.073
4.75	1345.72	0.091
4.55	1345.76	0.101
4.35	1345.80	0.130
4.15	1345.84	0.148
3.95	1345.88	0.189
3.75	1345.92	0.231
3.55	1345.97	0.273
3.35	1346.01	0.329
3.15	1346.05	0.374
2.95	1346.09	0.429
2.75	1346.13	0.451
2.55	1346.17	0.505
2.35	1346.21	0.560
2.15	1346.25	0.604
1.95	1346.29	0.645
1.75	1346.33	0.720

h / cm	t / h	w (g·cm^{-3})
1.55	1346.38	0.741
1.35	1346.42	0.765
1.15	1346.46	0.785

At IRC the analysis of the data was done using an optimization technique and the results are given below.

moisture concentration (g.cm^{-3})	diffusivity (m^2.s^{-1})
0.04	5.5E-10
0.06	3.3E-10
0.08	2.1E-10
0.1	1.6E-10
0.12	1.2E-10
0.14	1.0E-10
0.16	9.2E-11
0.18	8.7E-11
0.2	8.5E-11
0.22	8.6E-11
0.24	8.9E-11
0.26	9.4E-11
0.28	1.0E-10
0.3	1.1E-10
0.32	1.1E-10
0.34	1.2E-10
0.36	1.3E-10
0.38	1.3E-10
0.4	1.4E-10
0.42	1.4E-10
.44	1.4E-10
0.46	1.4E-10
0.48	1.4E-10
0.5	1.3E-10
0.52	1.3E-10
0.54	1.2E-10
0.56	1.2E-10
0.58	1.1E-10
0.6	1.1E-10
0.62	1.1E-10
0.64	1.2E-10
0.66	1.2E-10
0.68	1.4E-10
0.7	1.6E-10

moisture concentration (g.cm^{-3})	diffusivity (m^2.s^{-1})
0.72	2.0E-10
0.74	2.7E-10
0.76	4.0E-10

REFERENCES

1. Krus M. and Kießl K. NMR-measurement of capillary penetration behaviour of water and hydrophobic agent in porous stone and derivation of new capillary transport values, Research report, Fraunhofer-Institute of Building Physics, FtB-12e, 1991.

2. Kohonen R. A method to analyze the transient hygrothermal behaviour of building materials and components, Technical Research Centre of Finland Publications 21, 1984.

3. Kumaran M.K., Mitalas G.P., Ojanen T. and Kohonen R. Moisture Transport Coefficient of Pine form Gamma Ray Absorption Measurements , ASME Paper, HTD-Vol. 123, 1989, pp. 179-183.

4. Salonvaara M., A Transient Method to Determine Moisture and Heat Transport Coefficients of Porous Materials, Proceedings of the 2nd Symposium on Building Physics in the Nordic Countries, Trondheim, Norway, 1990, pp.355-360.

APPENDIX III

HYGROTHERMAL PROPERTIES OF BUILDING MATERIALS[1]

MASONRY BUILDING MATERIALS

1. *Bricks*

- Density : $830 \leq \rho \geq 1760$ kg/m³

THERMAL PROPERTIES

- Specific Heat Capacity : 840 J/(kg.K) (dry material)
- Thermal Resistance :

d = 14 cm : 1 / [0,98.exp(0,000994.ρ)] (m².K/W)
$860 \leq \rho \geq 1430$ kg/m³
θ = 20 °C, w = 0 kg/m³ r^2= 0.600; 13 meas.

d = 19 cm : 1 / [0,585.exp(0,001182.ρ)] (m².K/W)
$830 \leq \rho \geq 1630$ kg/m³
θ = 20 °C, w = 0 kg/m³ r^2= 0.962; 12 meas.

θ = 20 °C : $1 / [A_1 + A_2.u]$
(m².K/W)
$u \leq u_C$ (= cap.), u in %kg/kg

d(m)	ρ (kg/m³)	A_1	A_2	meas.	r^2
0.09	1470	7.94	0.397	3	1
0.14	863	2.09	0.09	8	0.98
	1100	3.35	0.18	4	0.93
	1120	2.72	0.28	3	1
	1180	3.37	0.31	3	1
	1200	3.13	0.32	3	1
	1240	4.17	0.38	3	0.99
	1360	2.96	0.34	3	1
	1430	4.17	0.42	3	0.99
0.19	800	1.53	0.096	3	1
	830	1.51	0.076	4	1
	880	1.83	0.13	3	1
	1100	2.41	0.094	10	0.64
	1140	2.26	0.13	3	1
	1650	4.00	0.34	3	1

---

[1] From Catalogue of Material Properties, IEA Annex 14 (upgraded version).

HYGRIC PROPERTIES

- Diffusion Thickness :equivalent value, included mortar joints

d(m)	spec.	samples	φ_m(%)	$[\mu d]_{eq}$(m)
0.09	bricks,	2	54	1.20
	6.5x9x19	1	86	0.51
0.09	bricks,	2	54	2.20
	acryl painted			
0.09	bricks,	1	86	0.65
	waterrepell.			
0.09	bricks,	2	86	4.00
	glazed			
0.19	bricks,	3	59	1.60
	6.5x9x19		81	0.61
0.20	bricks,	3	88	0.53
	6.5x9x19			
0.14	perfor.bricks	8	58	1.30
	14x19x29		84	0.84

AIR PROPERTIES

- Air Permeance : a.$(\Delta p)^b$ (m/(s.Pa))
  (Density of air flow in $m^3/(s.m^2)$)

d(m)	spec.	samples	a(.10^{-4})	b
0.09	handmade brick			
	4.5x9x19			
	not joined	6	4.6	-0.33
			σ = 3.7	0.06
	joined	3	0.29	-0.19
0.09	machine brick			
	6.5x9x19			
	not joined	9	27.6	-0.43
			σ = 21.6	0.09
	joined	3	0.32	-0.19
0.14	perforated brick			
	14x14x29			
	not joined	1	22.9	-0.41
	joined	3	0.18	-0.21
	plastered	1	0.095	-0.22

2. *Concrete blocks*

- Density : $860 \leq \rho \geq 1650$ kg/m³

THERMAL PROPERTIES

- Specific Heat Capacity : 840 J/(kg.K) (dry material)
- Thermal Resistance

  d = 14 cm : $1 / [0.73.\exp(0.00138.\rho)]$ (m².K/W)
  $860 \leq \rho \geq 1650$ kg/m³
  $\theta = 20$ °C, w = 0 kg/m³ $r^2 = 0.880$; 9 meas.

  $\theta = 20$ °C : $1 / [A_1 + A_2.u]$ (m².K/W)
  $u \leq u_C$ (= cap.), u in %kg/kg

d(m)	**ρ(kg/m³)**	**A_1**	**A_2**	**meas.**	**r^2**
0.12	980	2.92	0.12	3	1
0.14	1080	3.12	0.24	3	1
	1115	3.37	0.16	3	1
0.19	860	2.35	0.08	3	1

HYGRIC PROPERTIES

- Diffusion Thickness : equivalent value, included mortar joints

d(m)	**spec.**	**samples**	**φ_m(%)**	**$[\mu d]_{eq}$(m)**
0.14	blocks, 14x14x29	2	60	1.30
	960 kg/m³	2	86	0.54
0.14	blocks, 14x14x29	1	61	0.61
	1450 kg/m³	1	64	0.58
		1	83	0.61
		1	90	0.28

AIR PROPERTIES

- Air Permeance : a.(Dp)^b (m/(s.Pa))
  (Density of air flow in m^3/(s.m^2))

d(m)	spec.	samples	a(.10^{-4})	b
0.09	blocks, 9x9x19			
	1955 kg/m^3, joined	1	1.23	-0.12
	1927 kg/m^3, joined	1	1.61	-0.14
	1881 kg/m^3, joined	1	2.35	-0.18
0.14	hollow blocks, 14x19x39			
	987 kg/m^3, joined	1	1.69	-0.09
	954 kg/m^3, joined	1	3.46	-0.25
	910 kg/m^3, joined	1	5.13	-0.30
0.14	heavy hollow block, 14x14x29			
	not joined	1	33.6	-0.42
	joined	2	33.3	-0.27
	plastered	2	0.103	-0.23

3. Sand-lime stone

- Density : $1170 \le \rho \ge 1230$ kg/m^3

THERMAL PROPERTIES

- Specific Heat Capacity : 840 J/(kg.K) (dry material)
- Thermal Resistance :
  h = 20 °C : 1 / [$A_1 + A_2$.u]
  (m^2.K/W)
  u $\le u_C$ (= cap.), u in %kg/kg

d(m)	ρ (kg/m^3)	A_1	A_2	meas.	r^2
0.14	1140	4.07	0.24	3	1

HYGRIC PROPERTIES

- Diffusion Thickness : equivalent value, included mortar joints

d(m)	spec.	samples	φ_m(%)	$[\mu d]_{eq}$(m)
0.13	blocks	1	25	3.70

4. *Cellular Concrete*

- Density : $500 \leq \rho \geq 650$ kg/m³

THERMAL PROPERTIES

- Specific Heat Capacity : 840 (dry material) J/(kg.K)
- Thermal Resistance
  h = 20 °C : $1 / [A_1 + A_2.w]$ (m².K/W)
  $w \leq w_C$ (= cap.), w in kg/m³

d(m)	ρ(kg/m³)	A_1	A_2	meas.	r²
mortar:					
0.15	524	1.23	0.0067	6	0.99
	660	1.44	0.0073	6	1
glued:					
0.15	518	1.13	0.0059	6	0.99
	634	1.20	0.0074	6	0.99
mortar					
0.18	550	1.25	0.0094	4	1

AIR PROPERTIES

- Air Permeance : $a.(\Delta p)^b$ (m/(s.Pa))
  (Density of air flow in m³/(s.m²))

d(m)	spec.	samples	a(.10⁻⁴)	b
0.14	blocks, 14x24x60, 510 kg/m³			
	glued, open vertical joints	2	1.99	-0.39
	glued, closed vertical joints	1	0.83	-0.36
	plastered	1	0.11	-0.24

5. *Cavities*[1]

Thickness: 27 mm

- Apparent thermal conductivity (heat flow from top to bottom):

T(hot), °C	13.9	23.7	33.5
T(cold), °C	5.5	15.4	25.5
λ(apparent) W/(m.K)	0.115	0.126	0.147

---

[1] Data from the Laboratory of Building Physics, KU-Leuven.

6. CAVITIES WITH INTERIOR REFLECTIVE SURFACES [1]:

Thickness: 27 mm

- Apparent thermal conductivity (heat flow from top to bottom):

T(hot), °C	14.4	24.2	34.2
T(cold), °C	4.9	14.8	24.9
λ(apparent) W/(m.K)	0.0263	0.0275	0.0289

VARIOUS BUILDING MATERIALS

1. STRUCTURAL POLYURETHANE FOAM FOR THERMAL BREAKS IN WINDOW FRAMES:[1]

Thickness: 31.9 mm Density: 464 $kg.m^{-3}$

- Thermal conductivity

T(hot), °C	6.3	16.1	26.7	35.9
T(cold), °C	-2.9	7.0	17.0	26.8
λ, W/(m.K)	0.0671	0.0618	0.0629	0.0635

Thickness: 31.9 mm Density: 499 $kg.m^{-3}$

- Thermal conductivity :

T(hot), °C	5.9	16.0	26.0	35.7
T(cold), °C	-3.4	6.7	16.7	26.5
λ, W/(m.K)	0.0637	0.0649	0.0654	0.0662

Thickness: 32 mm Density: 614 $kg.m^{-3}$

- Thermal conductivity:

T(hot), °C	6.2	16.2	26.0	35.8
T(cold), °C	-2.6	7.3	17.1	26.9
λ, W/(m.K)	0.0923	0.0929	0.0940	0.0946

---

[1] Data from the Laboratory of Building Physics, KU-Leuven.

Thickness: 32 mm Density: 792 kg.m^{-3}

- Thermal conductivity:

T(hot), °C	5.9	15.9	25.7	35.5
T(cold), °C	-3.0	7.0	16.9	26.7
λ, W/(m.K)	0.110	0.111	0.112	0.113

2. *POLYMER CONCRETE*[1]

Thickness: 31.9 mm Density: 2204 kg.m^{-3}

- Thermal conductivity

T(hot), °C	3.9	13.5	23.6	33.3
T(cold), °C	-0.7	8.9	19.0	28.7
λ, W/(m.K)	1.59	1.63	1.64	1.68

Thickness: 52.2 mm Density: 1947 kg.m^{-3}

- Thermal conductivity

T(hot), °C	4.5	14.4	24.2	34.1
T(cold), °C	-1.5	8.4	18.2	28.2
λ, W/(m.K)	0.965	0.992	1.03	1.07

3. *POLYMER CEMENT*[1]

Thickness: 49.6 mm Density: 1869 kg.m^{-3}

- Thermal conductivity

T(hot), °C	5.2	15.0	24.7	34.5
T(cold), °C	-1.1	8.7	18.4	28.2
λ, W/(m.K)	0.752	0.761	0.778	0.788

4. *LIGHT- WEIGHT BRICK WORK*[1]

Thickness: 300 mm Density: 767 kg.m^{-3}

- Thermal conductivity

T(hot), °C	15.7	25.5	35.5
T(cold), °C	6.6	16.5	26.5
λ, W/(m.K)	0.217	0.223	0.226

---

[1] Data from the Laboratory of Building Physics, KU-Leuven.

- Thermal conductivity of moist material

T(mean), °C	10.8	10.8	20.5	20.5	30.4	30.4
u, (kg/kg)	0.024	0.062	0.024	0.062	0.024	0.062
λ, W/(m.K)	0.233	0.272	0.241	0.294	0.251	0.309

Thickness: 240 mm Density: 796 kg.m^{-3}

- Thermal conductivity

T(hot), °C	14.7	24.6	34.4
T(cold), °C	5.9	15.9	25.8
λ, W/(m.K)	0.194	0.200	0.202

- Thermal conductivity of moist material

T(mean), °C	10.3	10.3	20.3	20.3	30.0	30.0
u, (kg/kg)	0.032	0.066	0.032	0.066	0.032	0.066
λ, W/(m.K)	0.210	0.265	0.220	0.296	0.224	0.324

5. *POLYURETHANE FOAM (CARBON DIOXIDE BLOWN*[1]

Thickness: 117.7 mm Density: 32.6 kg.m^{-3}
Age: 6 months

- Thermal conductivity

T(hot), °C	15.0	24.6	35.0
T(cold), °C	5.2	15.0	25.4
λ, W/(m.K)	0.0302	0.0321	0.0328

Thickness: 118.2 mm Density: 32.8 kg.m^{-3}
Age: 6 months

- Thermal conductivity

T(hot), °C	14.7	24.3	34.5
T(cold), °C	4.8	14.7	24.9
, W/(m.K)	0.0280	0.0303	0.0310

---

[1] Data from the Laboratory of Building Physics, KU-Leuven.

6. *Poured Polyurethane*[1]

Thickness: 31.4 mm Density: 1144 kg.m^{-3}

- Thermal conductivity in the temperature range 2 to 31 °C is 0.185 W/(m.K).

7. *Polyamide* [1]

Thickness: 30.8 mm Density: 1338 kg.m^{-3}

- Thermal conductivity in the temperature range 1.5 to 31.5 °C is 0.40 W/(m.K).

8. *Gypsum Board Painted With Acrylic Paint (Primer + 2 Coats)*

- Water vapour permeance at 25 °C

RH1(%)	53.5	53.4	53.5	53.3	86.3	86.4	91.6	86.4
RH2(%)	69.6	69.6	69.6	85.8	96.9	96.8	96.9	96.8
δ_l kg.m^{-2}.s^{-1}.Pa^{-1}	1.2 x10^{-8}	8.44 x10^{-9}	1.2 x10^{-8}	7.6 x10^{-9}	5.7 x10^{-8}	5.0 x10^{-8}	5.4 x10^{-8}	6.3 x10^{-8}

9. *Bitumen Impregnated Polypropylene Foil*

Thickness 0.6 mm

- Water vapour permeability at 25 °C

RH1(%)	0	0	33	33	86	86
RH2(%)	52	52	86	86	97	97
δ kg.m^{-1}.s^{-1}.Pa^{-1} x10^{-15}	3.6	3.3	4.9	3.1	7.1	6.0

- Air permeability

Pressure difference Pa	50	100	150	200
k_a kg.m^{-1}.Pa^{-1}.s^{-1}	5.1x10^{-11}	3.4x10^{-11}	2.7x10^{-11}	2.3x10^{-11}

10. *Spunbonded Polyethylene (Tyvek)*

---

[1] Data from the Laboratory of Building Physics, KU-Leuven.

Thickness 0.2 mm

- Water vapour permeability at 25 °C

RH1(%)	0	0	37.5	37.5	89.5	89.5
RH2(%)	52	52	78.5	78.5	97.0	97.0
δ $kg.m^{-1}.s^{-1}.Pa^{-1}x10^{-13}$	7.0	8.3	12.5	12.5	41.8	25.7

- Air permeability

Pressure difference Pa	25	50	75	100	150	200
k_a $kg.m^{-1}.Pa^{-1}.s^{-1}$	$2.8x10^{-11}$	$2.8x10^{-11}$	$2.7x10^{-11}$	$2.7x10^{-11}$	$2.6x10^{-11}$	$2.6x10^{-11}$

11. POLYETHYLENE FOIL

Thickness 0.2 mm

- Air permeability

Pressure difference Pa	150	200
k_a $kg.m^{-1}.Pa^{-1}.s^{-1}$	$4.2x10^{-11}$	$4.56x10^{-11}$

12. BITUMINOUS GLASS-FIBRE (ON PUR)

Thickness 0.5 to 0.7 mm Mass per area 0.724 $kg.m^{-2}$

- Water vapour permeance at 26.7 °C

RH1(%)	0.1	75.0	92.0
RH2(%)	52.7	92.0	97.0
δ_l $kg.m^{-2}.s^{-1}.Pa^{-1}x10^{-12}$	9.0	10.0	18.5

- Water vapour permeance at 35.8 °C

RH1(%)	0.1	0.1	75.0	75.0	89.0	89.0
RH2(%)	50.0	50.0	89.0	89.0	97.0	97.0
δ_l $kg.m^{-2}.s^{-1}.Pa^{-1}x10^{-12}$	10.8	11.5	12.3	14.3	18.8	40.0

APPENDIX IV

ANNOTATED LIST OF PAPERS DISCUSSED AT VARIOUS ANNEX XXIV MEETINGS

1. Vapour Permeability. H. Hens (T3-B-92/03)

The standard cup method described by ASTM E 96, DIN 52 615, BSI DD146 and ISO/R1663 is used to determine the vapour transport characteristics of gypsum board, fibro-cement and PE-foil for three RH intervals, viz. 0 to 52 %, 52 to 86 % and 91.7 to 97 %. The importance of using the correct boundary RH conditions, especially at the higher RH range, for calculating the vapour permeance of the test specimens is emphasized.

2. Vapour Permeability: Moisture Dependent Or Not? H. Hens (T3-B-92/04)

The hypothesis that a constant vapour permeability together with grad RH as a second driving force to describe vapour transport through building materials is investigated, with reference to aerated concrete. The evidence does not favour such a hypothesis.

3. Vapour Permeability Of Lightweight Concrete And Expanded Polystyrene: Isothermal And Non-Isothermal Measurements. H. Hens, K. Vanherck And M. Goddeau (T3-B-93/01)

Vapour permeability measurements are done using the traditional isothermal cup method and a non-isothermal condensation method. The objective is to check the hypothesis that in the hygroscopic range both the vapour pressure and the relative humidity gradients are driving forces for vapour transport. The experimental data do not conform to this hypothesis.

4. Report On Experimental Investigation Of Thermally Induced Moisture Movement In Eastern White Pine. A. N. Karagiozis And M. K. Kumaran (T3-CA-91/01)

Gamma-ray attenuation method is used to determine transient moisture distribution within test specimens of eastern white pine, subjected to temperature gradients. The results are analyzed with a view to deriving information on thermal moisture diffusion coefficient.

5. Moisture Diffusivity Of Gypsum Board From Gamma-Ray Attenuation Measurements. M. K. Kumaran (T3-CA-93/03)

Isothermal water intake by specimens of gypsum board is investigated. Transient moisture distribution is determined using the gamma-ray attenuation method. A data reduction procedure to handle the inhomogenity of the specimens is introduced. The reduced data are analyzed in terms of the Boltzmann transformation to derive liquid moisture diffusivity as a function of moisture concentration.

6. Moisture Diffusivity Of Cellulose Insulation. R. G. Marchand And M. K. Kumaran (T3-CA-94/01)

Isothermal water intake by specimens of cellulose insulation is investigated. Transient moisture distribution is determined using the gamma-ray attenuation method. A secondary moisture transport process is identified. A data reduction procedure to handle the inhomogenity of the specimens is introduced. The reduced data are analyzed in terms of the Boltzmann transformation to derive liquid moisture diffusivity as a function of moisture concentration.

7. LATENITE: Hygrothermal Material Property Database. A. N. Karagiozis, M. Salonvaara And M. K. Kumaran (T3-CA-94/03)
Hygrothermal properties of many common building materials are collected and reduced in the form of analytical expressions for use in computer models.

8. Moisture Diffusivity Of Building Materials From Water Absorption Measurements. M. K. Kumaran (T3-CA-94/04)
The usefulness of the simple water absorption coefficient to estimate the magnitude of moisture diffusivity is examined.

9. Effect Of Functional Form Of Moisture Diffusivity On Moisture Absorption. M. Salonvaara And A. N. Karagiozis (T3-CA-94/06)
A 2-D computer model (LATENITE) is used simulate isothermal moisture intake process by brick specimens and compared with experimental data. In order to represent the transient moisture distribution correctly, the full functional dependence of moisture diffusivity should be used. Constant values or exponential approximations are unable to give the details of moisture transport.

10. Water Vapour Permeability Of Stagnant Air. M. K. Kumaran (T3-CA-95/02)
A brief literature review of information on binary diffusion coefficient of water vapour + air is reported. The continued use of Schrimer's equation to calculate water vapour permeability of stagnant air is found appropriate.

11. Effect Of Different Liquid Water Diffusivities For Wetting And Drying On The Moisture Behaviour. M. Krus (T3-D-92/01)
Measurements on sandstone show that the diffusivity calculated for water absorption process is one order of magnitude higher than that calculated for water redistribution during drying. A calculation of the water distribution in a monolithic wall of lime sandstone for one year shows that this difference in the transport property results in a much higher level of moisture content in the medium than projected by moisture diffusivity calculated using only the data on moisture absorption. Hence the importance of a hysteresis effect cannot be neglected.

12. Does Vapour Diffusion Really Depend On Moisture Content? M. Krus (T3-D-92/02)
It is hypothesized that vapour diffusion is caused by a vapour pressure gradient with a constant flow coefficient with a co-existing liquid transport in hygroscopic porous material, caused by a relative humidity gradient. The hypothesis is supported by non-isothermal permeability measurements.

13. Liquid Water Transport Above Capillary Saturation. M. Krus And H. Kunzel (T3-D-92/03)
Experimental data on water redistribution between capillary saturated and vacuum saturated test specimens of cellular concrete and lime sandstone are presented. The results show that a liquid water diffusivity cannot be defined above capillary saturation. The moisture content above capillary saturation serves merely as a reservoir for water transport below the capillary saturation moisture content.

14. Determination Of D_w From A-Value. M. Krus (T3-D-93/01)

Methods to use data on water absorption coefficient and capillary saturation moisture content to calculate moisture diffusivity as a function of moisture content are presented.

15. Non-Isothermal Moisture Movement In Wood: An Interpretation Of The Measurements Results Of Siau Et Al. M. Krus (T3-D-94/01)

Data from the literature are used to investigate the influence of hygroscopic moisture content on measured vapour permeability of wood. The hypothesis of two driving potentials, viz. vapour pressure gradient and gradient of RH (or suction or moisture content), is further examined. Under non-isothermal conditions these driving forces may have opposite directions. The measured vapour transport is the sum of vapour and liquid transport across the test specimen.

16. Experimental Determination Of Hygroscopic Properties Of Cement Pastes With Hysteresis Effects. B. Perrin And B. Dwi Agro (T3-F-94/01)

Cycles of sorption and desorption undergone by two cement pastes are investigated. The vapour permeabilities of the materials are determined and diffusivities calculated. The results indicate hysteresis effects.

17. Thermo-Hygrometric Performance Of Expanded Clay Concretes. P. Bondi And P. Stefanizzi (T3-I-91/01)

Seven different mixtures with a density range of 600 to 1000 $kg.m^{-3}$ are investigated. The hygroscopic moisture content depends on the cement content and relative humidity. Thermal conductivity depends on density and moisture content. Thermal diffusivity does not show any clear moisture or density dependence.

18. Moisture Measurement With NMR. L. Pel, K. Kopinga And H. P. Otten (T3-NL-92/01)

An equipment based on NMR is presented. Transient moisture distribution in building materials can be measured by this method.

19. The Estimation Of Moisture Diffusivity. M. De Wit And J. Van Schijndel (T3-NL-93/02)

Analytical methods to use data on water absorption coefficient and capillary saturation moisture content to calculate moisture diffusivity as a function of moisture content are presented; an exponential form of equation is proposed.

20. Thermal Properties Of Cellular Concrete With Specific Mass 560 $Kg.M^{-3}$. P. Matiasovsky And O. Koronthalyova (T3-SK-92/01)

Thermal conductivity of moist cellular concrete is determined. Experimental results obtained using a guarded hot plate method and a regular heating regime of the 1st kind under the 3rd kind boundary condition method agree well. The universal equation for calculating this quantity must contain information on pore size distribution.