International Energy Agency

Heat, Air and Moisture Transfer in Insulated Envelope Parts

Enquiry on HAMCaT Codes

Report Annex 24, Task 1, Modelling

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)

Task 1 - MODELLING

ENQUIRY ON HAMCaT CODES

Annex 24 participants

H. Hens, A. Janssens
K.U.-Leuven
Laboratorium Bouwfysica

CONTENTS

PREFACE

THE INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA) was established in 1975 within the framework of the Organisation for Economic Cooperation and Development (OECD) to implement an International Energy programme. A basic aim of the IEA is to foster cooperation among the 21 IEA Participating Countries to increase energy security through energy conservation, development of alternative energy sources and energy research, development and demonstration (RD&D). This is achieved in part through a programme of collaborative RD&D consisting of 42 Implementing Agreements, containing a total of over eighty separate energy RD&D projects.

ENERGY CONSERVATION IN BUILDING AND COMMUNITY SYSTEMS

As one element of the Energy Programme, the IEA sponsors research and development in a number of areas related to energy. In one of these areas, "Enery conservation in buildings and community systems", the IEA is backing various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programmes, building monitoring, comparison of calculation methods, energy management systems as well as air quality and inhabitants behaviour studies. Sixteen countries and the European Community:

BELGIUM, CANADA, CEC, DENMARK, GERMANY, FINLAND, GREECE, ITALY, JAPAN, NETHERLANDS, NEW ZEALAND, NORWAY, SWEDEN, SWITZERLAND, TURKEY, U.K., U.S.A.

have elected to participate and have designed contracting parties to the Implementing Agreement, covering collaborative research in this area. This designation by the government of a number of private organisations as well as universities and government laboratories as contracting parties, has provided a broader range of expertise to tackle the projects in the different technology areas than would have been the case if participation was restricted to governments. The importance of associating industry with government sponsored energy RD&D is recognised in the IEA, and every effort is made to encourage this trend.

THE EXECUTIVE COMMITTEE

Overall control of the programme is maintained by an Executive Commitee, which not only monitors existing projects but also identifies new area where collaborative effort may be beneficial. The Executive Committee ensures all projects to fit into a predetermined strategy without unnecessary overlap or duplication but with effective liaison and communication. Twenty-six projects have been initiated by the Executive Committee, of which the greater part has been completed:

ANNEX 1: Load energy determination of buildings (*)
ANNEX 2: Ekistics & advanced community energy systems (*)
ANNEX 3: Energy conservation in residential buildings (*)
ANNEX 4: Glasgow commercial building monitoring (*)
ANNEX 5: Air infiltration and ventilation centre (*)
ANNEX 6: Energy systems and design of communities (*)
ANNEX 7: Local government energy planning (*)
ANNEX 8: Inhabitants behaviour with regard to ventilation (*)
ANNEX 9: Minimum ventilation rates (*)
ANNEX 10: Building HVAC system simulation (*)
ANNEX 11: Energy auditing (*)
ANNEX 12: Windows and fenestration (*)
ANNEX 13: Energy management in hospitals (*)
ANNEX 14: Condensation and energy (*)
ANNEX 15: Energy efficiency in schools (*)
ANNEX 16: BEMS 1- User interfaces and system integration (*)
ANNEX 17: BEMS 2- Evaluation and emulation techniques
ANNEX 18: Demand controlled ventilation systems (*)
ANNEX 19: Low slope roof systems
ANNEX 20: Air flow patterns (*)
ANNEX 21: Energy efficient communities
ANNEX 22: Thermal modelling
ANNEX 23: Air flow modelling
ANNEX 24: Heat-, Air- and Moisture transport in new and retrofitted, highly Insulated Envelope parts (HAMTIE)
ANNEX 25: HEVAC real time simulation and fault detection
ANNEX 26: Air flow in large enclosures
ANNEX 27: Domestic Ventilation Systems
ANNEX 28: Low Energy Cooling

ANNEX 24: HEAT-AIR-MOISTURE TRANSPORT IN HIGHLY INSULATED ENVELOPE PARTS

The idea of starting an Annex on combined heat, air and moisture (HAM) transport in and through highly insulated envelope parts bases on the fact that in various countries of the EXCO a methodology to judge the effects of air and moisture flow on the instantaneous and average thermal performance, moisture behaviour and durability of the envelope is absent. An enquiry, kept in 1989, confirmed that view. In October 1990, a workshop was organised at the Leuven University, Belgium, focusing on the state of the art in the different countries. This workshop revealed a need for a better overall and applied knowledge on the level of HAM-modelling, environmental conditions and material property data as well as a need for a better use of experimental results. During that meeting, the Annex objectives were formulated as follows:

- to model and study in a fundamental way the physical phenomena of Heat, Air and Moisture (HAM) transport through new and retrofitted, highly insulated envelope parts;
- to analyse the consequences on the energetical and hygric performances and on the durability of the building envelope.

(*): completed

To reach these objectives, the annex was structured in 5 tasks:

<u>Task 1</u> *Model and Algorithm development*
This task not only includes improvements in modelling but also testing of simplified models with a potential to predict the combined effects of HAM-transport on insulation quality, hygric behaviour and durability.
Leading Country: Belgium

<u>Task 2</u> *Inside and external Environmental Conditions*
This task includes the choice of environmental parameters, a methodology of handling them and the development of sample sets of environmental conditions.
Leading country: United Kingdom

<u>Task 3</u> *Material and Layer Properties*
This task includes data collecting on thermal, hygric and air properties of materials and layers and substantial measuring work, especially on the moisture and air properties.
Leading country: Canada

<u>Task 4</u> *Experimental verification*
This task includes Hot Box and field tests on HAM-transport in envelope parts, comparison of the measured results with model prediction and transformation of the results into ΔU-rules and durability exigences.
Leading country: Germany

<u>Task 5</u> *Performances and Practice*
This task includes the translation of HAM-knowledge in correct design and execution of highly insulated new and retrofitted envelopes.

Highly insulated was defined as: $U \leq 0.30$ W/(m².K).

At first 10, later 14 countries joined together for 4 years of intensified research on HAM:

full BELGIUM, CANADA, DENMARK, FINLAND, GERMANY, ITALY, SWEDEN, SWITZERLAND, THE NETHERLANDS, U.K.

observer FRANCE, NORWAY, CZECH AND SLOVAK FEDERAL REPUBLIC, USA

The shared work included modelling, environmental conditions, material properties, experimental work, common exercises and the draft of interim and final reports. Also the national research efforts were scheduled in accordance with the Annex 24 scheme and the results brought together and used as base for the Annex publications.

Until now, 1 preparation, 1 starting and 3 working meetings of 3 days each were held to build up a common knowledge, to discuss research and reports and to elaborate a common performance rationale.

LIST OF EXPERTS CONTRIBUTING TO ANNEX 24

OPERATING AGENT

Belgium

K.U.Leuven, Laboratory of Building Physics,
represented by Prof. H. Hens, head of the lab.

NATIONAL EXPERTS, FULL MEMBERS

Belgium

National coordinator A. Janssens, K.U.Leuven, Laboratory of Building Physics

H. Hens, K.U.Leuven, Laboratory of Building Physics

F. Descamps, K.U.Leuven, Laboratory of Building Physics

P. Standaert, Physibel CV

Canada

National coordinator T. Hamlin, Canada Mortgage and Housing Corporation

M.K. Kumaran, NRC, IRC, Building Performance Section

A.N. Karagiozis, NRC, IRC, Building Performance Section

Denmark

National coordinator C.R. Pedersen Building Research Institute

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

Finland

National coordinator T. Ojanen VTT, Technical Research Centre of Finland

M. Salonvaara, VTT, Technical Research Centre of Finland

Germany

National coordinator K. Kießl Fraunhofer Institut für Bauphysik, Holzkirchen

H. Künzel, Fraunhofer Institut für Bauphysik, Holzkirchen

M. Krus, Fraunhofer Institut für Bauphysik, Holzkirchen

H. Stopp, Technische Universtät Cottbus, Angewandte Physik

Italy

National coordinator C. Lombardi Politecnico di Torino, Dipt. del Energetica

Sweden

National coordinator C.E. Hagentoft University of Lund, Dept. of Building Physics

J. Arfvidsson, University of Lund, Department of Building Physics

J. Claesson, University of Lund, Department of Building Physics

Switzerland

<u>National coordinator</u> P. Steiner
EMPA, Sektion Bauphysik

The Netherlands

<u>National coordinator</u> H. Oldengarm
TNO- Bouw

M. De Wit, T.U. Eindhoven, Faculteit Bouwkunde, FAGO
J. Wisse, T.U. Eindhoven, Faculteit Bouwkunde, FAGO
M.J. Van der Laan, T.U. Eindhoven, Faculteit Bouwkunde, FAGO

United Kingdom

<u>National coordinator</u> C. Sanders
BRE, Scottish Laboratory

P. Burberry, UMIST, Department of Building Engineering
R. Edwards, UMIST, Department of Building Engineering
G. Galbraith, Strathclyde University, Dept. of mechanical engineering
K. Johnson, Pilkington Insulation Ltd
H. Saidany, University of Bristol

NATIONAL EXPERTS, OBSERVERS

France

<u>National coordinator</u> P. Crausse (until 15 oct. 1992)
Institut de Mechanique des Fluides, Toulouse
B. Perrin
INSA-UPS, Dept de Genie Civil, Toulouse

T. Duforestel, CSTB
J.F. Daïan, Groupe Hydrology, Grenoble

Norway

<u>National coordinator</u> T. Jacobsen,
Building Research Institute, Trondheim

Slovak republic

<u>National coordinator</u> O. Koronthályová
Slovak Academy of Sciences, Institute of Construction and Architecture

P. Matiasovsky, Slovak Academy of Sciences, Institute of C. & A.

USA

<u>National coordinator</u> D.M. Burch
NIST, Gaithersburg

A. Tenwolde, Forest Products Laboratory, Madison

ENQUIRY ON EXISTING HAMCaT CODES

1. INTRODUCTION

As the first step in the modelling task of Annex 24 an enquiry on existing Heat-Air-Moisture Calculation Tools (HAMCaT) took place. At the end of July 1991, the enquiry form (see appendix 1) was distributed amongst all participating and observing countries, with a request to complete the form and to add a more detailed model and code descriptions.
By Januari 1993, completed forms and documentation on 29 codes from 10 countries were received, covering the whole Heat-Air-Moisture-Transfer (HAMT)-domain and ranging from simplified to very complex and complete models.

2. OVERVIEW OF HAMCaT CODES

	COUNTRY	INSTITUTE	MODEL NAME	TYPE OF TRANSFER
1.	Belgium	KU-Leuven,LB	Wand	1D Heat+Moisture
2.	Belgium	KU-Leuven,LB	Konvek	3D Heat+Air+Moisture
3.	Belgium	Physibel	Glasta	1D Heat+Moisture
4.	Belgium	KU-Leuven,LB	NatKon	2D Heat+Air
5.	Canada	University of Saskatchewan	HAMPI	1D Heat+Moisture
6.	Canada	CMHC	WALLDRY	1D Heat+Air+Moisture
7.	Canada	CMHC	WALLFEM	1D Heat+Air+Moisture
8.	Canada	TROW-CMHC	EMPTEDD	2D Heat+Air+Moisture
9.	Canada	NRC, IRC	LATENITE	2D Heat+Moisture
10.	Denmark	TU-Denmark Therm. Insul. Lab.	MATCH	1D Heat+Moisture
11.	Finland	VTT-Lab. of Heating and Ventilation	TRATMO2	2D Heat+Air+Moisture
12.	Finland	VTT-Lab. of Heating and Ventilation	TCCC2D	2D Heat+Air+Moisture
13.	France	INSA, Dep Genie -Civil, Toulouse	LTMB	1D Heat+Moisture
14.	France	Institut de Méca-nique des fluides Toulouse	CHEoH	2D Heat+Moisture
15.	France	Institut de Méca-nique des fluides Toulouse	TONY	2D Heat+Moisture
16.	France	CSTB	V30	1D Heat+Moisture
17.	France	CSTB	V320	2D Heat+Moisture
18.	Germany	Fraunhofer Institut für Bauphysik	WFTK	1D Heat+Moisture
19.	Germany	Fraunhofer Institut für Bauphysik	WUFIZ	2D Heat+Moisture
20.	Germany	TU-Cottbus Fachber. Physik+ Werkstoffe	JOKE	1D Heat+Moisture

Continuation

COUNTRY	INSTITUTE	MODEL NAME	TYPE of TRANSFER
21. Germany	TU-Cottbus Fachber. Physik+ Werkstoffe	COND	1D Heat+Moisture
22. Netherlands	TNO-Bouw, afdeling BBI	HYGRO	1D Heat+Moisture
23. Netherlands	TNO-Bouw, afdeling BBI	WISH-3D	3D Heat+Air
24. Sweden	SP	P1200A	1D Heat+Moisture
25. Sweden	Chalmers University of Technology	VADAU	2D Heat+Moisture
26. Sweden	Lund Universtity	AHCONP, ANHCONP	2D Heat+Air
27. Sweden	Gullfiber AB	FUKT74:6	1D Heat+Moisture
28. UK	BRE Scottish Laboratory	BRECON2	1D Heat+Moisture
29. USA	NIST	MOIST	1D Heat+Moisture

3. CLASSIFICATION AND COMPARISONS

3.1 General remarks

Some important remarks, preceeding further discussions, are:

- Although the conservation of energy equation is one of the basics in HAM-CaT-modelling, most codes are directed towards the simulation of hygric behaviour, not of thermal aspects: the influence of enthalpy flow and sensible heat-latent heat transformations on heat transfer, heat losses and heat gains. The only exceptions are the Heat + Air models, where heat flow calculation is one of the main purposes.
  To fulfill the objectives of the Annex, thermal outputs of most codes will therefore need to be upgraded;

- most HAMCaT-codes are research tools, more or less easy to use for the researcher-developer but difficult to work with for third parties.
  Only 6 of the 29 codes:

3.	Belgium	Physibel	Glasta
8.	Canada	TROW-CMHC	EMPTEDD
10.	Denmark	TU-Denmark Therm. Insul. Lab.	MATCH
21.	Germany	TU-Cottbus Fachber. Physik+Werk-stoffe	COND
26.	Sweden	Lund Universtity	AHCONP, ANHCONP

28.	UK	BRE, Scottish Laboratory	BRECON 2

are commercially available, that means, sold to interested users. Of the 23 other, 9 report a users friendly input module:

1.	Belgium	KU-Leuven,LB	Wand
2.	Belgium	KU-Leuven,LB	Konvek
4.	Belgium	KU-Leuven,LB	NatKon
6.	Canada	CMHC	WALLDRY
7.	Canada	CMHC	WALLFEM
19.	Germany	Fraunhofer Institut für Bauphysik	WUFIZ
23	Netherlands	TNO-Bouw, afdeling BBI	WISH-3D
25.	Sweden	Chalmers University of Technology	VADAU
27.	Sweden	Gullfiber AB	FUKT 74:6

while 4 mention the code being transferred to other institutions:

10.	Finland	VTT-Lab. of Heating and Ventilation	TRATMO2
23.	Netherlands	TNO-Bouw, afdeling BBI	WISH-3D
25.	Sweden	Chalmers University of Technology	VADAU
27.	Sweden	Gullfiber AB	FUKT 74:6

This proves that HAM-performance oriented design and development of building parts is still not normal practice. Most building envelopes are in fact designed and constructed, based on experience ("we know this is a good solution"), with an implicit acceptance of future failures. This is not a firm base to explore new solutions nor to guarantee performance.

3.2 Overall classification of HAMCaD-codes

Although the 29 HAMCaD-codes are different in one way or another, have specific features and show varying degrees of simplification, a classification in order of overall complexity of the implemented model appeared possible, resulting in 9 types, from very simple to most complete, with type 9 as reference:

TYPE 1

Steady state Glaser scheme of heat conduction and vapour diffusion with constant material properties. Thermal-hygric link: the $p_{sat}(T)$ equation of state:

1.	Belgium	KU-Leuven,LB	Wand
22.	Netherlands	TNO-Bouw, afdeling BBI	HYGRO
28.	UK	BRE, Scottish Laboratory	BRECON 2

TYPE 2

Steady state Glaser scheme of heat conduction and vapour diffusion, corrected on capillary moisture transfer. Constant material properties. Thermal-hygric link: the $p_{sat}(T)$ equation of state:

3.	Belgium	Physibel	Glasta

TYPE 3

Non steady state heat and vapour transfer, material properties a function of the moisture ratio. Thermal-hygric link: the $p_{sat}(T)$ equation of state and latent heat:

5.	Canada	University of Saskatchewan	HAMPI

TYPE 4

Non steady state heat, vapour and liquid transfer. Material properties a function of the moisture ratio (and temperature). Thermal-hygric link: the $p_{sat}(T)$-equation of state and latent heat:

9.	Canada	NRC, IRC	LATENITE
10.	Denmark	TU-Denmark Therm. Insul. Lab.	MATCH
13.	France	INSA,Dep Genie-Civil Toulouse	LTMB
14.	France	Institut de Méca-nique des fluides Toulouse	CHEoH
15	France	Institut de Méca-nique des fluides Toulouse	TONY
16.	France	CSTB	V30
17.	France	CSTB	V320
18.	Germany	Fraunhofer Institut für Bauphysik	WFTK
19.	Germany	Fraunhofer Institut für Bauphysik	WUFIZ
20.	Germany	TU-Cottbus Fachber. Physik+ Werkstoffe	JOKE
21.	Germany	TU-Cottbus Fachber. Physik+ Werkstoffe	COND
24.	Sweden	SP	P1200A
25.	Sweden	Chalmers University of Technology	VADAU
27.	Sweden	Gullfiber AB	FUKT 74:6
29.	USA	NIST	MOIST

TYPE 5

Steady and non steady state heat and air transport. Constant material properties. Thermal-air link: enthalpy transfer (and stack effect)

4.	Belgium	KU-Leuven,LB	NatKon

23	Netherlands	TNO-Bouw, afdeling BBI	WISH-3D
26.	Sweden	Lund Universtity	AHCONP ANHCONP

TYPE 6

Steady state uncoupled heat, vapour and air transport. Constant material properties. Heat-mass link: the $p_{sat}(T)$-equation of state, latent heat, enthalpy transfer (and stack effect)

2.	Belgium	KU-Leuven,LB	Konvek
8.	Canada	TROW-CMHC	EMPTEDD

TYPE 7

Steady state heat and air transfer and non steady state vapour transfer with constant material properties and as link between heat and mass transfer, the $p_{sat}(T)$-equation of state, latent heat, enthalpy transfer and stack effects

6.	Canada	CMHC	WALLDRY

TYPE 8

Non steady state heat, vapour and air transfer. Material properties function of moisture ratio and temperature. Link between heat and mass transfer: the $p_{sat}(T)$-equation of state, latent heat, enthalpy transfer and stack effects

12.	Finland	VTT-Lab. of Heating and Ventilation	TCCC2D

TYPE 9

Non steady state heat, vapour, liquid and air transfer. Material properties function of moisture ratio (and temperature). Link between heat and mass transfer: the $p_{sat}(T)$-equation of state, latent heat, enthalpy transfer and stack effects

7.	Canada	CMHC	WALLFEM
11.	Finland	VTT-Lab. of Heating and Ventilation	TRATMO2

The classification shows that:
- most, i.e. 15 codes belong to type 4. This type can be seen as the ultimate development when hygric behaviour of envelope parts, composed of capillary porous materials, is the major objective. Within type 4, one can still differentiate between more simplified codes (COND, FUKT 74:6) and others.
- Heat+Air+Moisture Transfer in its overall complexity appears more intensively analysed and modelled in countries with a wood frame building tradition as Canada, Finland and Sweden than in countries with a stony wall tradition. An explanation may be the greater sensitivity to convection induced concealed condensation and to convective heat losses of wood frame than stony wall envelopes and the more critical moisture behaviour and higher number of moisture failures with wood.

3.3 Purpose of the HAMCaD-codes

Some codes have been developed to cover all types of envelope parts, others have a more restricted applicability. The first we call 'general', the second 'specific'. One could expect a relation between the overall complexity of the model and its generality in the sense of: the higher the complexity of the model, the more general its use. This however is not always true, as is proven by the matrix 'type versus specific to general'. From specific to general, a 4 step scale is used:

1–very specific, developed to solve a well defined problem
2–specific, may be used for 1 or a few types of constructions
3–rather general, may be used for all types of constructions as far as no vented cavities are present
4–general, can be used for vented and non vented constructions

MODEL	TYPE 1	2	3	4	5	6	7	8	9
					PURPOSE				
1.B, Wand	3								
2.B, Konvek						4			
3.B, Glasta		3							
4.B, NatKon					1				
5.C, HAMPI			1						
6.C, WALLDRY							1		
7.C, WALLFEM									4
8.C, EMPTEDD						2			
9.C, LATENITE				3					
10.DK, MATCH				3					
11.SF, TRATMO2									4
12.SF, TCCC2D								4	
13.F, LTMB				1					
14.F, CHEoH				1					
15.F, TONY				1					
16.F, V30				3					
17.F, V320				3					
18.G, WFTK				3					
19.G, WUFIZ				3					
20.G, JOKE				3					
21.G, COND				3					
22.NL, HYGRO	3								
23.NL, WISH-3D					2				
24.S, P1200A				2					
25.S, VADAU				3					
26.S, AHCONP,					2				
ANHCONP					2				
27.S, FUKT 74:6				3					
28.UK, BRECON 2	4								
29.US, MOIST				4					

The generality of a code not only depends on the overall complexity of the model but also on the specific physical expression of basic laws, on the mathematical tools used and on software-linked elements.

PHYSICS

Two examples:

- If the moisture content is choosen as humidity potential, the applicability of the code restricts itself to single material envelope parts. Most of these 'potential-moisture content' models in fact were developed to simulate cellular concrete parts;
- Although an advanced moisture transfer approach may be incorporated, some of the type 4 codes do not go beyond the hygroscopic moisture content range, excluding all problems of 'contact with liquid water' (rain, rising damp, interstitial condensation, initial moisture content).

...

MATHEMATICS

- in solving 1 specific problem some codes simplify the mathematics to such an extent, that general use is no longer possible nor allowed;
- the choice of one or another solution rationale may exclude application of a code when rather quick phenomena must be simulated

....

SOFTWARE-LINKED

- data bases offered could narrow the field of application to only one or a few construction parts;
- a software induced limitation of the number of control volumes may impede a more general application;
- imput may be so restricted that only 1 typical problem can be programmed;

....

<u>It must be clear that if a widespread use of HAMCaD codes is the objective, the next generation software should be as general as possible</u>.

3.4 Intrinsic complexity of the model

Under intrinsic complexity, we understand amongst other factors:

- the way material properties are handled;
- the way heat exchanges in cavities and air spaces are modelled;
- the way the surface heat, vapour, air and water flows are treated;
- the way indoor boundary conditions are introduced.
- the way outdoor boundary conditions are introduced.
- initial conditions

MATERIAL PROPERTIES

The choices in the codes are:

1. *Transfer and capacitive properties constant*
2. *Some transfer and capacitive properties a function of moisture content*
3. *All transfer and capacitive properties a function of moisture content*
4. *All transfer and capacitive properties a function of moisture content, some a function of moisture content and temperature*

Matrix:

MODEL	TYPE 1	2	3	4	5	6	7	8	9
1.B, Wand	1								
2.B, Konvek						1			
3.B, Glasta		1							
4.B, NatKon					1				
5.C, HAMPI			2						
6.C, WALLDRY							1		
7.C, WALLFEM									3
8.C, EMPTEDD						1			
9.C, LATENITE				3					
10.DK,MATCH				3					
11.SF,TRATMO2									4
12.SF,TCCC2D								4	
13.F, LTMB				4					
14.F, CHEoH				3					
15.F, TONY				3					
16.F, V30				3					
17.F, V320				3					
18.G, WFTK				3					
19.G, WUFIZ				3					
20.G, JOKE				3					
21.G, COND				2					
22.NL,HYGRO	1								
23.NL,WISH-3D					1				
24.S, P1200A				2					
25.S, VADAU				3					
26.S, AHCONP,					1				
ANHCONP					1				
27.S, FUKT 74:6				3					
28.UK,BRECON 2	1								
29.US,MOIST				2					

As for the applicability, there is no direct relation between overall complexity of the model and the way material properties are handled.

HEAT EXCHANGES IN CAVITIES AND AIR SPACES
The choices in the codes are:

1. *Cavities are modelled as conductive layers with an equivalent thermal conductivity*
2. *Cavities are modelled as conductive layers but enthalpy flow along the cavity is taken into account*
3. *A net distinction is made between convection (+conduction), enthalpy flow and radiation*

Matrix:

MODEL TYPE	1	2	3	4	5	6	7	8	9
1.B, Wand	1								
2.B, Konvek						2			
3.B, Glasta		1							
4.B, NatKon					3				
5.C, HAMPI			1						
6.C, WALLDRY							2		
7.C, WALLFEM									2
8.C, EMPTEDD						1			
9.C, LATENITE				1					
10.DK,MATCH				1					
11.SF,TRATMO2									3
12.SF,TCCC2D								3	
13.F, LTMB				1					
14.F, CHEoH				1					
15.F, TONY				1					
16.F, V30				1					
17.F, V320				1					
18.G, WFTK				1					
19.G, WUFIZ				1					
20.G, JOKE				1					
21.G, COND				1					
22.NL,HYGRO	1								
23.NL,WISH-3D					3				
24.S, P1200A				1					
25.S, VADAU				1					
26.S, AHCONP,					2				
ANHCONP					2				
27.S, FUKT 74:6				1					
28.UK,BRECON 2	2								
29.US,MOIST				2					

SURFACE HEAT, VAPOUR AND WATER FLOW

The choices in the codes are:

1.Use of surface film coefficients;

2.Distinction between radiation and convection, use of a surface film coefficient for vapour transfer

3.Use of surface film coefficients for heat and vapour transfer, surface moisture content for water transfer

4.Use of surface film coefficients for heat and vapour transfer, imposed surface air pressure

5.Distinction between radiation and convection, use of a surface film coefficient for vapour transfer, imposed surface air pressure or air flow

Matrix:

MODEL TYPE	1	2	3	4	5	6	7	8	9
1.B, Wand	1								
2.B, Konvek						4			
3.B, Glasta		1							
4.B, NatKon					1				
5.C, HAMPI			1						
6.C, WALLDRY							4		
7.C, WALLFEM									5
8.C, EMPTEDD						4			
9.C, LATENITE				1					
10.DK,MATCH				1					
11.SF,TRATMO2									4
12.SF,TCCC2D								4	
13F, LTMB				1					
14.F, CHEoH				1					
15.F, TONY				1					
16.F, V30				1					
17.F, V320				1					
18.G, WFTK				1					
19.G, WUFIZ				1					
20.G, JOKE				1					
21.G, COND				1					
22.NL,HYGRO	1								
23.NL,WISH-3D					1				
24.S, P1200A				1					
25.S, VADAU				1					
26.S, AHCONP,					2				
ANHCONP					2				
27.S, FUKT 74:6				1					
28.UK,BRECON 2	2								
29.US,MOIST				1					

INDOOR BOUNDARY CONDITIONS

The choices in the codes are:

1.Temperature
2.Temperature, air pressure
3.Temperature, vapour pressure (or RH, or dew point)
4.Temperature profile, vapour pressure ((or RH, or dew point)
5.Temperature, vapour pressure ((or RH, or dew point), air pressure
6.Temperature profile, vapour pressure ((or RH, or dew point), air pressure

Matrix:

MODEL	TYPE 1	2	3	4	5	6	7	8	9
1.B, Wand	3								
2.B, Konvek						5			
3.B, Glasta		3							
4.B, NatKon					1				
5.C, HAMPI			3						
6.C, WALLDRY							5		
7.C, WALLFEM									5
8.C, EMPTEDD						5			
9.C, LATENITE				3					
10.DK,MATCH				3					
11.SF,TRATMO2									6
12.SF,TCCC2D								6	
13.F, LTMB				3					
14.F, CHEoH				3					
15.F, TONY				3					
16.F, V30				3					
17.F, V320				3					
18.G, WFTK				3					
19.G, WUFIZ				3					
20.G, JOKE				3					
21.G, COND				3					
22.NL,HYGRO	1								
23.NL,WISH-3D					2				
24.S, P1200A				3					
25.S, VADAU				3					
26.S, AHCONP,					2				
ANHCONP					2				
27.S, FUKT 74:6				3					
28.UK,BRECON 2	3								
29.US,MOIST				3					

Here, a clear link between type and boundary condition is found. This is a very logical observation: if one wants to calculate air flows through an envelope part, differences in air pressure must be introduced. If one wants to evaluate interstitial condensation by diffusion, temperature and vapour pressure, RH or dewpoint are needed. If stack effects are a point of concern, indoor temperature profiles are a must...etc

It is not always clear what is meant by temperature: air temperature, black globe temperature, comfort temperature?

OUTDOOR BOUNDARY CONDITIONS

The choices in the codes are:

1. *Temperature*
2. *Temperature, vapour pressure (or RH, or dew point)*
3. *Temperature, air pressure*
4. *Temperature, vapour pressure (or RH, or dew point), air pressure (through wind velocity..)*
5. *Temperature, vapour pressure (or RH, or dewpoint), clear sky long wave radiation*
6. *Temperature, vapour pressure (or RH, or dewpoint), solar gains, clear sky long wave radiation*
7. *Temperature, vapour pressure (or RH, or dewpoint), solar gains, clear sky long wave radiation, air pressure (through wind velocity)*
8. *Temperature, vapour pressure (or RH, or dewpoint), solar gains, (clear sky long wave radiation), rain*
9. *Temperature, vapour pressure (or RH, or dewpoint), solar gains, clear sky long wave radiation, air pressure (through wind velocity) rain*

Matrix:

MODEL TYPE	1	2	3	4	5	6	7	8	9
1.B, Wand	6								
2.B, Konvek						4			
3.B, Glasta		6							
4.B, NatKon					1				
5.C, HAMPI			1						
6.C, WALLDRY							7		
7.C, WALLFEM									9
8.C, EMPTEDD						4			
9.C, LATENITE				6					
10.DK,MATCH				6					
11.SF,TRATMO2									9
12.SF,TCCC2D								9	
13.F, LTMB				2					
14.F, CHEoH				2					
15.F, TONY				2					
16.F, V30				2					
17.F, V320				2					
18.G, WFTK				8					
19.G, WUFIZ				8					
20.G, JOKE				8					
21.G, COND				2					
22.NL,HYGRO	6								
23.NL,WISH-3D					3				
24.S, P1200A				8					
25.S, VADAU				6					
26.S, AHCONP,					1				
ANHCONP					1				
27.S, FUKT 74:6				6					
28.UK,BRECON 2	5								
29.US,MOIST				6					

Clear sky radiation and rain are not always introduced in a very sophisticated and correct way. For example: a surface moisture content may simulate driving rain, clear sky radiation is substituted by a drop in outdoor temperature of 5°C. In reality, driving rain starts as a surface flow and ends as contact with liquid water and clear sky radiation depends on slope, cloudiness and long wave emissivity of the surface.

In 4 codes, the concept of equivalent temperature for moisture calculations is introduced, combining in 1 'fictive' temperature the air temperature, solar gains, clear sky long wave radiation and the multiplier effect of the non linear 'saturation pressure - temperature' - relation:

1.	Belgium	KU-Leuven,LB	Wand
3.	Belgium	Physibel	Glasta
22.	Netherlands	TNO-Bouw, afdeling BBI	HYGRO
27.	Sweden	Gullfiber AB	FUKT 74:6

This concept seems interesting for simplified heat and moisture transfer calculations on daily, weekly or monthly mean basis. It should be explored more deeply.

INITIAL CONDITIONS

The possibilities are linked to the type. In type 5 codes, moisture transfer is not considered. In type 1 and type 6 codes, dry materials are the only choice. In all other types, hygroscopic moist or wet materials may be the starting condition. This is the real world situation.

4. DISCUSSION

As pointed out under 2, each code has its proper features and simplifications. However, a sound explanation of why certain simplifications are introduced is not always given nor explained. Is it because otherwise the mathematics becomes too complicated, or is it because physics and a random test on problem cases showed the simplified approach gave reliable results..?
Therefor, as a discussion added to this existing code overview, some critical aspects of modelling are mentioned and explored.

4.1 Basic equations

All codes start from **the conservation of energy and mass laws**, stating that in an infinitesimal volume the energy and mass in- or outflow (div $\dot{q}$, div $\dot{m}$) must equal the change in energy and mass content ($\partial Q/\partial t$, $\partial M/\partial t$), including local sources or sinks (S_E, S_M):

energy $$\mathrm{div}\ \dot{q} = \frac{\partial Q}{\partial t} + S_E$$

mass $$\mathrm{div}\ \dot{m} = \frac{\partial M}{\partial t} + S_M$$

Both conservation laws are paradigms of classic physics.

To calculate densities of flow rate, all codes accept linear **'density of flow rate - gradient of potential' relations** (heat conduction, diffusion, unsaturated water flow, pressure flow...):

heat	*mass*
$\dot{q} = - A_H \text{ grad } P_H$	$\dot{m} = - A_M \text{ grad } P_M$

with A_H and A_M the 'conductivities'.

When simultaneous mass and energy transfers are considered, most codes explicitely or implicitely apply irreversible thermodynamics, stating that energy and mass flow must depend of the same potentials, one per component present. This gives as the system of equations:

$$\text{div}(A_{H1}\text{grad } P_1 + A_{H2}\text{grad } P_2 + ..) = \frac{\partial Q}{\partial t} + S_E$$

$$\text{div}(A_{M1}\text{grad } P_1 + A_{M2}\text{grad } P_2 + ..) = \frac{\partial M}{\partial t} + S_M$$

....

These equations are also found by purely physical reasoning, including enthalpy flow and bulk mass transfer (for example: vapour in the air) in the energy and mass balances. Physics are in any case needed to quantify the transport coefficients A_{H1}, A_{H2}, A_{M1},... However, not all models apply irreversible thermodynamics in a complete way, i.e. use the same potentials for heat and mass transfer. A reason may be that the judgement of importance allows the elimination of influences. For example: enthalpy flow, coupled to liquid flow may be disregarded, omitting the liquid flow potential from the heat transfer equation.

However, all equilibrium equations, stating that at each moment a balance exists between 'velocity of flow' and 'driving potentials', ignore the dynamics of transfer. Only one code:

14.	France	Institut de Méca- nique des fluides Toulouse	CHEoH

mentions that problem and proposes as the density of flow rate equations:

heat	*mass*
$\tau_H . \frac{\partial \dot{q}}{\partial t} + \dot{q} = -A_H \text{ grad } P_H$	$\tau_M . \frac{\partial \dot{m}}{\partial t} + \dot{m} = -A_M \text{ grad } P_M$

with τ_H and τ_M the dynamic time constants of heat and mass flow. In heat conduction τ_H can be neglected ($\tau_H < 10^{-9}$ s). In mass transfer, there may be a question mark: is it negligible or not?

The last type of equations needed to solve HAMT-problems are the **equations of state**, linking potentials together or potentials to capacitive properties. Known and in use in most codes are:

- the 'water vapour saturation pressure - temperature' equation of state ($p_{sat}(\theta)$);
- the relation between capacitive heat and temperature;
- the sorption isotherms, relating moisture content to RH and temperature;
- the retention curve, relating moisture content to suction.

4.2 Potentials

As far as **heat** transfer alone is concerned, there is a general agreement that temperature θ (°C), T (K) is the correct potential. No code for example takes the capacitive heat as (fictitious) potential.

As the potential for **moisture** flow however, a variety of possibilities is proposed in the different codes, to some extent dependent on whether or not vapour and liquid flow are combined.

When only **vapour flow** is supposed, the potentials in use are:

- vapour pressure p_v (Pa)
  This choice goes back to Ficks law of diffusion.
- vapour concentration ρ_v (kg/m^3)
  Also this choice is based on Ficks law of diffusion.
- relative humidity φ (-) and temperature θ (°C)
  Goes back to:

$$p = \varphi \cdot p_{sat} \qquad \text{with} \quad p_{sat} = f(\theta).$$

When **liquid flow** is included, the potentials used become:

- vapour pressure p_v (Pa) and liquid pressure s (Pa)
- moisture content w (kg/m^3) and temperature θ (°C)
- vapour pressure p_v (Pa), moisture content w (kg/m^3) and temperature θ (°C)
- vapour pressure p_v (Pa) and temperature θ (°C)
- vapour pressure p_v (Pa) and relative humidity φ (-)
- relative humidity φ (-), temperature θ (°C) and moisture content w (kg/m^3)
- universal potential for liquid flow and vapour pressure for vapour flow
  The universal potential Φ is defined as:

$$0 \le \varphi \le 0.9: \Phi = \varphi$$
$$\varphi > 0.9 \quad : \Phi = 1.7 + 0.1 \log r \text{ with } r = \text{equivalent pore radius}$$

- vapour concentration ρ_v (kg/m^3) and moisture content w (kg/m^3)

When **air flow** is added, the potential in use is:

- air pressure p_a (Pa)
  Stack effect is included by adding gravity forces to pressure. This however could also be done by using as potentials air pressure and temperature.

In this overall list of liquid flow potentials, moisture content is the only fictitious one. Moisture content in fact is a capacitive quantity, as is the capacitive heat content, not a potential! It is therefore never continuous in contact surfaces between materials.
The so called universal potentials are mathematical tricks, an attempt to by-pass the mathematical difficulties that real liquid potentials as suction, vapour pressure, RH...impose. Suction indeed gives very large difference in value for small differences in moisture content, vapour pressure and RH on the other hand stay in a very narrow potential-interval near saturation for large differences in moisture content.

The choice for one or another set of potentials could depend on:

- *the kind of material*
  . non hygroscopic, non capillary materials (=very wide pores)
  . hygroscopic, non capillary materials (=very small pores)
  . non hygroscopic, capillary materials (=wide pores)
  . hygroscopic, capillary materials (=small pores)

  As an envelope part in most cases is a composite of different kinds of material, a universal model should perhaps include different sets of potentials, one for each kind of material, with an automatic switch from one set to another through the equations of state.

- *the moisture interval*
  . hygroscopic
  . above-hygroscopic
  . above capillary

- *the type of model*
  . simplified
  . complex (reference)

A more correct justification of choices is in any case welcomed.

4.3 Hysteresis

Moisture behaviour of materials shows hysteresis in all equations of state and (perhaps) in the flow properties. Only 2 codes explicitely mention the effect:

10.	Denmark	TU-Denmark Therm. Insul. Lab.	MATCH
14.	France	Institut de Mécanique des fluides Toulouse	CHEoH

Code 10 proposes a very simple solution: to take a mean between the drying and wetting lines. Code 14 discusses a model to account for the effect and shows that it may be important when rather quick changes in moisture content occur. All other codes accept that the phenomenon exists but with only a marginal influence on the results. Question mark: is this true?

4.4 Material properties: dependency of potentials, anisotropicity?

Simple codes, such as the type 1, 2, 3, 5 and 6, use constants as material properties. The more fundamental codes introduce dependencies, especially due to moisture content, some from moisture content and temperature. In most cases the functional relation property-potential is defined experimentally. However, it could be a good point to study more in detail the physics behind some of these experimentally measured properties. A clear example is the so called vapour permeability, derived from a cup test, where a relationship with RH is accepted.

One more fundamental model:

19.	Germany	Fraunhofer Institut für Bauphysik	WUFIZ

works with constant permeabilities linked to gradients in vapour pressure and explains the variation through liquid flow, activated by gradients in RH. This seemed proven by non isothermal cup tests, where vapour pressure gradient and RH-gradient had opposite sign, with as result: a smaller steady state moisture flow than in isothermal tests with identical vapour pressure and RH-gradient, but with the same sign.

Two other codes:

16.	France	CSTB	V30
17.	France	CSTB	V320

also include liquid flow in vapour permeability, but point the temperature influence on this liquid flow as the cause of differences in the results between isothermal and non isothermal vapour permeability tests. Such discussions ask for clarification.

In general, not only the transfer terms in the governing equations are functions of the driving potentials but also the capacitive term. They should therefor be developed into a series of potential-time partial derivates. If for example 2 potentials are in the game, than the result is:

$$\frac{\partial Q}{\partial t} = B_{H1}\frac{\partial P_1}{\partial t} + B_{H2}\frac{\partial P_2}{\partial t}$$

$$\frac{\partial M}{\partial t} = B_{M1}\frac{\partial P_1}{\partial t} + B_{M2}\frac{\partial P_2}{\partial t}$$

B_{H1}, B_{H2}, B_{M1}, B_{M2} stand for the 'specific capacitive properties' of the material, again all functions of the driving potentials. Of course, in a number of cases, some of these coefficients may be taken as constant or will be ≈ 0. However, a more thorough analysis is welcomed.

The anisotropic nature of materials is implemented in 4 codes:

9.	Canada	NRC, IRC	LATENITE

11.	Finland	VTT-Lab. of Heating and Ventilation	TRATMO 2
12.	Finland	VTT-Lab. of Heating and Ventilation	TCCC2D
26.	Sweden	Lund Universtity	AHCONP, ANHCONP

Especially in air transfer, anisotropic behaviour may be very pronounced and needs further exploration.

4.5 Sources and sinks

A well known mass sink is the evaporation of liquid, a well known mass source the condensation of liquid. If present, the heat of evaporation or condensation results in a heat sink or source. Apart of this however, in the lower hygroscopic range also the heat of adsorption intervenes.
Most codes, except:

16.	France	CSTB	V30
17.	France	CSTB	V320

neglect it. Again, we have to put a question mark: can it be allowed or not?

4.6 Air transport

10 of the 29 codes integrate air transport in the model. Of those, 4 look at the combination heat and air transport and 6 link air transfer to heat and moisture transfer. Of these 6, only 4

2.	Belgium	KU-Leuven,LB	Konvek
7.	Canada	CMHC	WALLFEM
11.	Finland	VTT-Lab. of Heating and Ventilation	TRATMO2
12.	Finland	VTT-Lab. of Heating and Ventilation	TCCC2D

are real HAMT-codes: they include cavity flow as well as permeable materials, permeable layers and leaks and they can be applied to different envelope parts. Introducing air transfer in the models is not an easy task, neither from a mathematical point of view nor from a geometrical point of view:

- If one aims to develop a very general model, then perhaps the only possibility is to combine the Navier Stokes equations of flow with a turbulence model, the conservation of heat and mass (air, moisture) laws, surface heat radiation and convection and mass transfer at the surface. This leads to an overall FEM- or CVM-simulation of the envelope part, based on the simultaneous solution of 6 or more equations. Major difficulties in the development are the mathematical stability of the solution and the choice of the turbulence model. As far as permeable materials are concerned, Navier Stokes simplifies to a simple linear flow equation, to combine with the continuity equation for air, a '$\text{div}\ \dot{m}_a = 0$'-expression. This makes solution much easier.

The Navier Stokes approach is to some extend used in:

7.	Canada	CMHC	WALLFEM
11.	Finland	VTT-Lab. of Heating and Ventilation	TRATMO2
12.	Finland	VTT-Lab. of Heating and Ventilation	TCCC2D

- A more simple but less accurate way is to transform the envelope part in a hydraulic network of resistances and to use the network theory to come to a system of non linear equations with the air pressures in the nodal points as unknowns. See:

2.	Belgium	KU-Leuven,LB	Konvek

- air flow calculations necessitate a very detailed description of the envelope part, with information on leaks, flow paths, overlaps..etc. In most cases these data are not available.

Nevertheless, air transport is one of the most important parts of HAMT-modelling, both from a heat as from a vapour transfer point of view. Air flow in fact may augment heat transfer in a very decisive way and increase vapour transfer to a multiple of diffusion. Liquid flow and build up of moisture content also cause air flow in capillary-porous materials, while air flow may result in liquid flow.

A further development of complex codes, including air transfer, and the implementation of air transfer in simplified codes are two of the challenges to be tackled in the modelling part of the Annex. This supposes a renewed interest in measuring air permeabilities of materials and air permeances of layers.

4.7 Performances

Only 6 models include in one or another way performance checks:

1.	Belgium	KU-Leuven,LB	Wand
3.	Belgium	Physibel	Glasta
8.	Canada	TROW-CMHC	EMPTEDD
21.	Germany	TU-Cottbus Fachber. Physik+Werkstoffe	COND
22.	Netherlands	TNO-Bouw, afdeling BBI	HYGRO
28.	UK	BRE Scottish Laboratory	BRECON 2

and give warnings when problems could be expected. Most performance lists however are rather primitive. A typical example is wood, where the u=20% kg/kg moisture ratio is taken as upper limit, without any reference to temperature, although it is well known that temperature plays a decisive role in wood decay.

5. CONCLUSIONS

Looking at the impressive number of 29, one could say that developing HAMT-models and codes is no longer a challenge. The preceeding text however clarifies that still a number of questions remain:

On the level of modelling:
- allowable and acceptable simplifications in physics?
- thermal modules?
- air transport?
- potentials?
- correct definition of and relation between transfer and capacitive properties and potentials?
- hysteresis?
- sources and sinks: heat of adsorption?

...

On the level of boundary conditions
- the concept of equivalent temperature for moisture calculations?
- driving rain?
- representative indoor-outdoor air pressure differences?
- modelling of the indoor climate?

On the level of contact conditions
- Moisture contact: When capillary? When only diffusion or diffusion + bulk transport? Influence of gravity (drainage)?
- Air flow: contacts acting as flow paths or not?

On the level of initial conditions
- Initial moisture content of different materials?

On the level of performances

Introducing in existing and new codes in one or another way an expert system, based on accurate performance knowledge and choices.

6. REFERENCES

1. Anderlind G., *Classification of model FUKT 74:6*, IEA-Annex 24 Internal Report T1-S-91/05, Gullfiber AB, Billesholm
2. Burch D.M., Thomas W.C., *An Analysis of Moisture Accumulation in a Wood Frame Wall Subjected to Winter Climate*, NISTIR 4674, National Institute of Standards and Technology, october 1991
3. Castenmiller C., *Classification of model HYGRO*, IEA-Annex 24 Internal Report T1-NL-91/01, TNO-Bouw, afdeling BBI, Delft
4. Duforestel T., *Classification of models V30 & V320*, IEA-Annex 24 Internal Report T1-F-91/04, CSTB, Champs-sur-Marne
5. Hagentoft C.E., *Classification of models AHCONP/ANHCONP*, IEA-Annex 24 Internal Report T1-S-91/04, Lund University, Lund
6. Häupl P., Stopp H., Strangfeld P., *Classification of models JOKE & COND*, IEA-Annex 24 Internal Report T1-D-91/03, TU Cottbus, Fachbereich Physik und Werkstoffe, Cottbus
7. Hedberg B., *Classification of model VADAU*, IEA-Annex 24 Internal Report T1-S-91/03, Chalmers University of Technology, Div. of Building Materials, Göteborg
8. Hens H., *Classification of model KONVEK*, IEA-Annex 24 Internal Report T1-B-91/02, Labo Bouwfysica KU Leuven
9. Hens H., *Classification of models (enquiry and example)*, IEA-Annex 24 Internal Report T1-B-91/01, Labo Bouwfysica KU Leuven
10. Karagiozis A., *Overview of the 2-D hygrothermal heat-moisture transport model LATENITE*, IEA-Annex 24 Internal Report T1-CA-93/01, National Research Council Canada, Institute for Research in Construction, Ottawa.
11. Kerestecioglu A., Jhinger H., Hamlin T., *Classification of model WALL-FEM*, IEA-Annex 24 Internal Report T1-CA-91/03, Canada Mortgage and Housing Corporation, Montreal
12. Kiessl K., *Classification of model WFTK*, IEA-Annex 24 Internal Report T1-D-91/01, Fraunhofer Institut für Bauphysik, Holzkirchen
13. Künzel H.M., *Classification of model WUFIZ*, IEA-Annex 24 Internal Report T1-D-91/02, Fraunhofer Institut für Bauphysik, Holzkirchen
14. Lecompte J.,*The influence of the stack effect on the thermal quality of insulated cavity constructions, doctoral dissertation*, KU Leuven, 1989
15. Lemaire T., *Classification of model WISH-3D*, IEA-Annex 24 Internal Report T1-NL-91/03, TNO-Bouw, afdeling BBI, Delft
16. Molenda C.H.A., Crausse P., *Classification of model CHEoH, Capillary Hysteresis Effects on Humidity/Heat-transfer*, IEA-Annex 24 Internal Report T1-F-91/01, Institut de Mécanique des Fluides, Toulouse
17. Ojanen T., *Classification of model TCCC2D*, IEA-Annex 24 Internal Report T1-SF-91/02, Laboratory of Heating and Ventilation, VTT, Espoo
18. Pedersen C.R., *Classification of model MATCH*, IEA-Annex 24 Internal Report T1-DK-91/01, Thermal Insulation Laboratory, TU Denmark, Lyngby
19. Perrin B., *Classification of model LTMB*, IEA-Annex 24 Internal Report T1-F-91/02, INSA Département Genie-Civil, Toulouse
20. Prat M., *Classification of model TONY*, IEA-Annex 24 Internal Report T1-F-91/03, Institut de Mécanique des Fluides, Toulouse

21. Reginato M., Handegord G., Rousseau J., *Classification of model EMPTIEDD, Envelope Moisture Performance through Infiltration, Exfiltration, Diffusion and Drainage*, IEA-Annex 24 Internal Report T1-CA-91/04, TROW ltd, Montreal
22. Salonvaara M., *Classification of model TRATMO2*, IEA-Annex 24 Internal Report T1-SF-91/01, Laboratory of Heating and Ventilation, VTT, Espoo
23. Sandberg P.I., *Classification of model P1200A*, IEA-Annex 24 Internal Report T1-S-91/02, SP Swedish National Testing Institute, Borås
24. Sanders C.H., *Classification of model BRECON2*, IEA-Annex 24 Internal Report T1-UK-91/01, BRE Scottish Laboratory, Glasgow
25. Standaert P., *Classification of model GLASTA*, IEA-Annex 24 Internal Report T1-B-91/03, Labo Bouwfysica KU Leuven
26. Swinton M., *Classification of model WALLDRY.1*, IEA-Annex 24 Internal Report T1-CA-91/02, Canada Mortgage and Housing Corporation, Montreal
27. Tao Y.-X., Besant R.W., *Classification of model HAMPI, Heat and Moisture Transport in Porous Insulation*, IEA-Annex 24 Internal Report T1-CA-91/01, Department of Mechanical Engineering, University of Saskatchewan, Saskatoon

APPENDIX

1. CLASSIFICATION FORM

IEA- ANNEX 24/ TASK 1

HAMCaM MODELS

Model Name	....

Country ....

Author name ....

address ....

....

---

1 COMBINATION?

- 1.1 Heat and Moisture ☐
- 1.2 Moisture and Air ☐
- 1.3 Heat and Air ☐
- 1.4 Heat, Air and Moisture ☐

2. TIME DEPENDANCY?

- 2.1 Steady State ☐
- 2.2 Non Steady State ☐

3. SPACE DEPENDANCY?

- 3.1 One Dimension ☐
- 3.2 Two Dimensions ☐
- 3.3 Three Dimensions ☐

4. HANDLING HEAT- AIR AND MOISTURE TRANSFER IN AN ENVELOPE PART

If Heat+ Moisture (= 1.1) are combined, only fill in 4.1 and 4.2

If Moisture+ Air (= 1.2) are combined , only fill in 4.2 and 4.3

If Heat+ Air (= 1.3) are combined, only fill in 4.1 and 4.3

If Heat+ Air+ Moisture are combined, fill in 4.1, 4.2, 4.3

4.1 Heat	Equivalent conduction	☐
	Conduction, cavity convection and radiation	☐
	Equivalent conduction and enthalpee flow	☐
	Equivalent conduction and latent heat flow	☐
	Eq. conduction, enthalpee and latent heat flow	☐
4.2 Moisture	Vapour, by diffusion	☐
	Vapour, by diffusion and convection	☐
	Moisture, by suction	☐
	Moisture, by relative suction(1)	☐
4.3 Air	Only cavity flows	☐
	Only flow through air open layers	☐
	Cavity flow and flow through air open layers	☐
	Forced flow (wind or pressure induced)	☐
	Stack flow (temperature induced)	☐
	Forced and Stack flow	☐

(1) Relative suction: integrating suction, gravity force and external pressure

5. POTENTIALS AND MATERIAL PROPERTIES

A clear distinction is made between heat, vapour, moisture and air transfer. If the model is steady state, skip the capacitive term questions.

5.1 Heat transfer by conduction

Is described by using as material property:

- the thermal conductivity as a constant ☐
- the thermal conductivity as a function of moisture content ☐
- the thermal conductivity as a function of moisture content and corrected on latent heat release ☐
- other:..
  ....
  ....

The potential is:

- the temperature ☐

The capacitive term is defined by:

- the volumetric heat capacity ☐

Remarks..
....
....
....
....
....
....
....

5.2 Vapour

Is described by using as material and layer property:

<u>materials</u>

- the vapour conductivity as a constant ☐
- the vapour conductivity as a function of RH ☐

<u>layers</u>

- the vapour resistance as a constant ☐
- the vapour resistance as a function of RH ☐

<u>other</u>:...

....

....

The potentials are:

- the vapour concentration ☐
- the vapour pressure ☐
- temperature and RH ☐
- other:...

....

....

The capacitive term is defined by:

- the specific moisture content, related to the sorption isotherm ☐
- other:...

....

....

Remarks...

....

....

....

....

....

....

....

5.3 Moisture, water

Is described by using as material property:

the moisture conductivity as a fuction of moisture content ☐

the moisture diffusivity as a function of moisture content ☐

the moisture conductivity and the thermal diff. coefficient ☐

other:...

....

....

The potentials are:

suction ☐

the moisture content ☐

temperature ☐

other:...

....

....

The capacitive term is defined by:

the specific moisture content, related to the water retention curve

other:...

....

....

Remarks..

....

....

....

....

....

....

....

5.4 Air

Is described by using as material or layer property:

materials

the air permeability ⊔

layers

the air permeance ⊔

other:...

....

....

The potentials are:

air pressure ⊔

temperature ⊔

other:...

....

....

A capacitive effect is taken into account ⊔

is not taken into account ⊔

Remarks...

....

....

....

....

....

....

....

6. BOUNDARY CONDITIONS

6.1 Climatological Parameters, taken into account

Indoor		outdoor	
air temperature	☐	air temperature	☐
relative humidity	☐	insolation	☐
vapour pressure	☐	clear sky IR radiation	☐
air pressure	☐	relative humidity	☐
		vapour pressure	☐
		wind pressure	☐
		rain	☐

6.2 Surface flows, taken into account

- heat flow (i.e. a radiative flow) ☐
- vapour flow ☐
- air flow ☐
- condensation or water flow ☐

6.3 Time scale

If non steady state:	hourly mean	☐
	daily mean	☐
	mixed (i.e. a different scale for the thermal and hygric part..)	☐
If steady state:	weekly mean	☐
	monthly mean	☐
	yearly mean	☐

6.4 Implementation of climatological parameters

Outdoor

- combined (i.e. temperature+ insolation in 1 parameter) ☐
- not combined ☐

Indoor

- 1 value (f.e. 1 air temperature) ☐
- functional relation (f.e. indoor air temperature= f(height)) ☐

6.5 Remarks...

....

....

....

7. **THE STATUS OF THE MODEL SOFTWARE.**

developed as research tool, only the author can use it	☐
developed as research tool with a users friendly input	☐
used by other institutions	☐
commercially available	☐

DESCRIPTION OF THE MODEL:

Theoretical background, equations, examples solved