ABSTRACT
This paper summarizes two sets of activities that were undertaken in a Subtask on “Indoor Boundary Conditions”, as part of the International Energy Agency Annex 41. Field monitoring in Europe, Scandinavia and Canada provided new information on moisture excess and vapour pressure excess in dwellings. This information is presented in comparison with existing indoor climate classes as stipulated in various European standards. The classifications do not agree with the new information in the details. The deviations differ from country to country. In the second part of this paper, calculations using four simple models for generating information on indoor temperature and relative humidity are examined in comparison with field data. The models tested were the European Indoor Class Model, the BRE model, and the ASHRAE 160P simple and intermediate models. The ASHRAE intermediate model seemed to be the most robust exhibiting lower errors when compared to measured data. The European Indoor Class also performed well and can be used when data regarding moisture generation and/or air change rates is not available. The BRE procedure is problematic and generally exhibits large positive errors for most of the houses surveyed. The ASHRAE simple model is not appropriate for use since it exhibits large errors and does not trend well with the measured conditions.

KEYWORDS
Indoor, Temperature, Humidity, Moisture excess, Models

INTRODUCTION
The International Energy Agency’s Annex 41 on “Whole Building Heat, Air and Moisture (HAM) Response, MOIST-ENG” is being carried out through four Subtasks. One of these Subtasks (Subtask 3) deals with “boundary conditions” as appropriate to assessing the HAM responses. Within this Subtask many international participants researched on “indoor boundary conditions”. This paper briefly presents two of the accomplishments of these international efforts.

Subtask 3 of Annex 41 was given the responsibility to define the exterior and interior hygrothermal loads for subsequent use in whole building HAM analyses. Exterior loads are predominately governed by the weather details. Interior loads depend on weather parameters, but also depend on the interior details of the building as well as the activities, human or otherwise, within the building. The task that is related to interior loads in the Annex is aiming to characterize “ indoor moisture releases” and “interior temperature set point profiles”.

To meet the above objective of the Subtask, many field investigations were carried out by participating countries from Europe, Scandinavia and North America. Majority of the investigations were on low occupancy, single family homes. Few investigations included apartments and school buildings. In all these investigations the dwellings were characterised in terms of ventilation strategies, air exchange rates, volume, number of occupants and construction details. The measurements invariably included indoor relative humidity and temperature at discrete intervals in selected rooms. Information was also gathered on outdoor weather parameters. The data gathered from these investigations were
statistically analysed to derive information on quantities such as moisture generation rate, moisture excess or excess vapour pressure, daily variations in relative humidity and temperature and air leakage characteristics. Some of the data were also used to check various simplified models that are currently used to predict the hourly variations in indoor relative humidity in dwellings. This paper presents information on the moisture excess or excess vapour pressure from various international investigations, in comparison with the “Indoor Climate Classes” (ICC) that are included in various international standards such as EN ISO 13788 (2001) and BS 5250 (2002). It also summarises the results of the comparison between model predictions of variations in indoor relative humidity and field data.

**Indoor Climate Classes**

The concept of indoor climate classes is used in various European and Scandinavian Standards to classify different types of dwellings, in terms of the severity of the indoor moisture load. The origin of this classification can be traced back to a Swedish investigation (Sandberg 1995). The difference between indoor and outdoor water vapour pressure was called the “excess vapour pressure” and based on the magnitude of this quantity in relation to the outdoor temperature, dwellings were classified into five classes. This idea was carried over to various international standards in different formats, two of which are schematically shown in Figures 1 and 2. The quantity called moisture excess in Figure 2 is the difference between the indoor and outdoor moisture concentrations in air.

![Figure 1. Indoor climate classes in terms of the excess vapour pressure in dwellings.](image)

When the indoor humidity load corresponds to the range between 0 and 270 Pa (or 0 and 2 g m$^{-3}$) in the flat segments in Figures 1 and 2, the ICC is called very low, and the other ranges in the increasing order are called, low, moderate, high and very high above 1080 Pa (or 8 g m$^{-3}$). In the British standard BS 5250, according to the same scheme, dwellings are classified into humidity classes 1 to 5 in the increasing order of moisture load. Other standards identify these five classes with storage, shops and offices, low occupancy dwellings, high occupancy dwellings and special buildings respectively.
FIELD INVESTIGATIONS

Working papers that were presented during the Annex meetings reported field investigations on indoor conditions from Finland, Estonia, Belgium, Canada, Slovakia, Germany, Spain and England. The Finnish investigation (Kalamees et al. 2005) included 101 lightweight timber-frame, single family detached homes; the Estonian (Kalamees and Vinha 2006), 27 detached houses and 14 apartments; the Belgian (Janssens and Vandepitte 2006, Hens 2004, Hens et al. 2004), 18 social houses, 17 private single family houses of moderate sizes, four other single family houses, 11 individual rooms in four separate student homes and 18 class rooms from 18 different schools; the Canadian (Rousseau et al. 2007), three sets of eight single family homes from three different climatic regions; the Slovakian (Mihalka and Matiasovsky 2006), three separate flats in large panel buildings; the German (Holm et al. 2005), 12 rooms in 11 separate buildings; the English (Ridley et al. 2007), about 1600 dwellings (called Warm Front Houses) and the Spanish (Rodriguez Saurez et al. 2006), class rooms from seven schools.

![Diagram](image)

Figure 2. Indoor climate classes in terms of moisture excess in dwellings.

All the above investigations recorded at least hourly information on indoor relative humidity and temperature at selected locations together with detailed information on outdoor boundary conditions, for weeks or months. Wherever applicable, the investigations gathered information on air exchange rates, air leakage characteristics, ventilation strategies, pressure differences, occupancy rates and the physical characteristics of the buildings.

STATISTICAL ANALYSES OF THE FIELD DATA

Detailed statistical analyses of the data from Finland, Estonia and Belgium (on houses) arrived at similar conclusions as follow. Design moisture excess for houses with low occupancy on the 10 % critical level is +4 g/m² during the cold period (T_{out} ≤ +5 °C) and +1.5 g/m² during the warm period (T_{out} ≥ +15 °C). Between these cold and warm period levels, the moisture excess decreases linearly. In addition to the moisture excess, the room temperature design curve was determined. During the heating season, the daily average room temperature was 21°C at an outdoor temperature of -25°C and rises up to 23°C at an outdoor temperature of 15°C. The daily average temperature rises to 27°C at a daily average outdoor temperature of 25°C for summer. The upper and lower 10 % level differ by 2°C from the
average temperature. When the indoor air is humidified to 25 % RH, the moisture excess increases by 1g/m². The average moisture production during winter was 5.9 kg/day/house and hence 1.9 kg/day/person. An average value of daily maximum moisture production was 12.7 kg/day/house or 4.0 kg/day/person. These values may be regarded as the upper limit for sensitivity analyses of these houses. Results from the statistical analyses of the data from Estonia are summarised in Figure 3. The data from all measurements were consolidated to give a 10 % critical level of moisture excess as a function of the outdoor temperature. This was called a design curve. This design curve is compared with the boundaries prescribed in the EN ISO 13788 in Figure 3. Though for most part the design curve falls in the lower region for low occupancy dwellings, the following deviations are noticeable:
1. The constant part (4 g/m²) does not end at 0°C, but at 5°C.
2. The moisture excess does not become “zero” at 20°C but reaches a limiting value (1.5 g/m²) at 15°C.

Information derived on moisture excess from other locations widely differed from that expected for low occupancy dwellings as is stipulated in the European standard. For the Belgian student residences, there is no specific pattern or value for the moisture excess in the 11 rooms. Each occupant has individual behaviour that can make the room fall anywhere in the five indoor climate classes. The 18 class rooms in the Belgian investigation appear to be operating in the very low and low regions of the ICC. Canadian homes fall mostly in the high or very high categories. Out of the three Slovakian flats, one falls well within the moderate load range while the other two are clearly in the low range. Majority of the 10 German buildings operate in the very low to low ranges of the ICC. Analyses of the English data resulted in a new ICC proposal as shown in Figure 4.
CALCULATING INDOOR HUMIDITY AND TEMPERATURE

When HAM simulation tools are used to investigate the performance of the building envelope or to carry out investigative work, the setting of the exterior and interior boundary conditions are critical. Exterior boundary conditions are generally obtained from various sources of weather or climatic data. When considering the performance of the building envelope, two important interior conditions are the temperature and the moisture content of the interior air. The interior moisture load plays an important role in occupant comfort, health and safety, as well the durability of the building envelope. When measured data are available it can be used directly as input for the interior boundary conditions. More generally, however, information on measurements of interior conditions is lacking and is often simulated using predictive models. Often the interior boundaries conditions are modeled by either assuming constant conditions or using the simple HVAC set points. More detailed models simulating the interior conditions are available. These models use readily available data, such as the ambient temperature and atmospheric moisture content, occupancy and use information, in addition to some basic building characteristics.

Closely related to the objective of the subtask activities, several publications in the past 25 years that have presented procedures to calculate indoor relative humidities can be identified. One can start from the work of Tsuchiya (Tsuchiya 1980) on "Infiltration and indoor air temperature and moisture variation in a detached residence". Though Jones in a 1995 review (Jones 1995) dismisses Tsuchiya’s work of "historical interest only", all the essential inputs to calculate indoor humidity were identified in that work. Kusuda (Kusuda 1983) has presented Tsuchiya’s equations, which contain terms to represent moisture generation rate, moisture absorbed by the room surfaces, ventilation rate, vapour condensation rate on surfaces and humidity ratios of the room air and the outdoor air among other physical characteristics of the building and its surroundings. Various aspects that were presented in Tsuchiya’s equations can be
seen in all subsequent publications. Jones (Jones 1995) presents seven “current humidity models” in the review. Fundamentally, there are no major differences among the seven procedures. They differ only in details and in the nature of the assumptions. One can write the following generalized equation (1) and do justice to all the seven procedures that were identified by Jones.

\[
p_i = p_i(V_0, T_i, T_e, p_e, p_i', n_{source}, n_{sink})
\]  

where,

\( p_i' \) and \( p_i \) = the water vapour pressure inside a building at an initial time and after a given interval respectively

\( V_0 \) = the total inside volume of the building

\( T_i \) and \( T_e \) = the exterior and interior thermodynamic temperatures respectively

\( p_e \) = the water vapour pressure of the exterior air

\( n_{source} \) = the amount of substance of water vapour that is newly added to the room air in the given interval

\( n_{sink} \) = the amount of substance of water vapour that is newly removed to the room air in the given interval

Procedures, such as those in ASHRAE Standard 160P (2002), introduced since the review of Jones also do not deviate from the basics in Equation (1). In an exercise in the Annex activities, four of the simpler procedures that are currently available for the calculation of indoor RH in dwellings were chosen and tested against the field data from the Canadian investigations. The four models selected here were: the BRE model, the European Indoor Class Model (CEN 2005), the ASHRAE 160P Intermediate Model, and the ASHRAE 160P Simplified Method.

**COMPARISON OF FIELD DATA WITH CALCULATED RH**

Four models, for predicting the indoor relative humidity in houses, were tested against measured relative humidity data for 25 houses in Canada. The houses were typical of older North American construction methods. In assessing the models it should be noted that only 1 month of measured data used for comparison with predicted results. The month used was typical of the most extreme conditions occurring at the measurement sites. The RH in each house was measured in two different locations producing 50 different data sets. Hourly predictions were made using the four models and compared with the average hourly observations.

When compared with the measured data all the models generally overestimated the RH in the space. The ASHRAE intermediate model seemed to be the most robust exhibiting lowest Mean Bias Error (MBE), Mean Absolute Error(MAE), and Root Mean Squared Error (RMSE). The European Indoor Class also performed well for such a simple model and can be used when data regarding moisture generation and/or air change rates is not available. As a design tool however it should be noted that this model is not consistently conservative in predicting the indoor RH. The BRE is problematic and generally exhibits positive MBE’s as well large RMSE’s for the North American houses survey. This model should be used with caution as the \( \alpha \) and \( \beta \) coefficients are probably not appropriate for the type of houses monitored, as was noted by Jones. The ASHRAE simple model exhibits large positive MBE’s and large RMSE’s as well. It does not trend well with measured data, especially when the interior conditions change with the exterior environment. This model was developed for design purposes and should be used as last resort even as a design tool. For colder climates overestimates of the design RH could lead to the unnecessary winnowing of cheaper more efficient designs. For models that use ventilation rates as a primary input it is imperative that these be determined accurately, as the models are very sensitive to changes in the ventilation rates especially at lower range.
CONCLUDING REMARKS
The Annex is now working in the reporting phase of the project. Reports on “indoor boundary conditions” have included further details of what have been summarised above. In addition, information has been gathered from various sources on moisture sources and moisture generation rates and tabulated. Another section deals with surface film coefficients as needed in HAM calculations. Both heat and mass transfer coefficients are narrated. Yet another section reports on pressure differences that are encountered in buildings.

REFERENCES