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# Moisture supply in Danish single-family houses – the influence of building style

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**Abstract**

According to ISO 13788 internal moisture supply in dwellings can be described by humidity classes defined by outdoor temperature, occupancy and ventilation. Hygrothermal measurements in 500 Danish single-family houses were made to investigate if building style and geographical location are important as well. Further it was investigated whether snapshot measurements in materials could replace logging of relative humidity and temperature. Building type has only a limited effect on the moisture supply. Geographical location has an effect; however variations are not systematic. It is not possible by means of two-pin or capacitive moisture meter measurements to estimate indoor relative humidity.


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*Keywords:* Building style; capacitive moisture meter; dwellings; geography; humidity class; hygrothermal sensor; moisture supply; two-pin moisture meter

## 1. Introduction

Since 1995, the seller of a house in Denmark can be insured against claims from the buyer by requesting an offer for insurance, based on an inspection documented in a Home Condition Report (HCR) made by a building expert [1]. The HCR should lay out the condition of the house compared to what can be expected from a house of similar type and age with a typical/normal level of maintenance. The building inspection is visual with the option of using simple hand-held instruments, if relevant, but with no destructive measures allowed. It has been discussed to let the inspection

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include a snapshot of the moisture conditions to indicate whether a specific house has an increased level of moisture compared to what is "acceptable" [2].

Knowledge on when mold growth happens at non-stationary conditions is lacking and it is very individual at what level people's health is affected. The acceptable level could therefore be based on a combination of what is normal for Danish dwellings and at what conditions mold growth is expected to take place. However, statistical based knowledge on what is a normal moisture level in Danish houses does not exist.

Measurements were performed in 508 Danish mainly owner occupied single-family houses at different time of year to test if humidity class 2 according to [3] represents normal level of moisture. Humidity classes are based on interrelated values of *moisture excess* – difference between outdoor and indoor moisture content expressed in g/m$^3$ – named *moisture supply* in this paper, and outdoor temperature, depending on the use of buildings. The hypothesis in this paper is that moisture conditions in houses depend on building style including design of building element, i.e. the layer structure, materials included etc., not considered by [3]. Influence of occupant behavior is the subject of another paper presented at the conference [4]. Further details concerning the study are described in [5].

## 2. Research method

Moisture supply in a house is determined by moisture production and ventilation rate, both regarded as being mainly dependent on occupant behavior, but may also be caused by the house itself. As the moisture production may be affected by the choice of building materials and building style. Similarly, the ventilation rate will be dependent on air tightness of the house and type of ventilation, mechanical or natural. Occupant behavior is difficult to distinguish from the influence of the house itself, unless a study includes many houses of a specific building style, which is the case in this study on Danish single-family houses.

Based on changes in building style and use of building materials seven building types were defined, consisting of two types representing the period before 1910 – with and without timber framing – and four types after, one of these covering wooden houses. Summer cottages are treated as a separate type, no matter the type of materials used, as these are not occupied full time. Although in the Danish building stock the number of houses per type are not the same it was decided in the study to select the same amount of houses of each type, as building types with few houses (timber framing and summer cottages) varies quite a lot in style, while a more common building type (houses built 1960-1979) are relatively homogeneous. Selection of houses and type of information collected is described in [4]. To cover seasonal variations the investigation was spread out over a whole year.

It is possible to measure moisture content in the air of a building during a short visit, but the value may change fast, e.g. if the room is aired. Materials on the other hand react slowly; measurements of moisture content in materials although being a snapshot may give a good picture of the moisture content level. To cover both snapshot measurements and measurements for a longer period ensuring a more detailed picture of the moisture conditions, the following instruments were used to assess the moisture conditions:

- *Hygrothermal sensors* logging indoor climate (temperature and relative humidity) two times per hour for 14 days (EL-USB 2+ from Lascar). In each hose 3-5 sensors were placed, typically in bathrooms, living rooms and bedrooms, i.e. not all rooms in all houses are included in the study. An extra sensor was placed outside.
- A moisture meter working as a *two-pin moisture meter* in wooden constructions and *capacitive moisture meter* at mineral based materials (MO290 from Extech Instruments).

## 3. Results

### *3.1. Measurements of indoor climate (temperature and relative humidity) with hygrothermal sensors*

Measurements of temperature and relative humidity (RH) were converted into moisture content (g/m$^3$) in the air for both indoor and outdoor measurements. For each type of building an average value for each of the rooms included in the study was calculated. Further, average values of indoor temperature, indoor relative humidity and moisture supply for each room and for each house as a whole were calculated. Figure 1a shows the distribution of average moisture supply for each room where a sensor was placed (in total about 1600 rooms in 500 houses). The typical average moisture supply lies between 0 and 2.5 g/m$^3$.

*3.2. Snapshot measurements*

Both when using two-pin moisture meter and capacitive moisture meter, measurements were made at “representative” areas as well as visible moist areas. Snapshot measurements with two-pin moisture meter were made mainly in wooden floors, floor panels and ceilings, results expressed as moisture content in weight-%. Results will be between 7 weight-% (lower detection limit) and 28 weight-% (moisture saturated wood). Measurements with capacitive moisture meter were made in different rooms in a house, exactly which rooms and where in the rooms varied, depending on the decor of the house and how homogeneous the rooms seemed in regard to moisture conditions based on the experience of the inspector. The values are reported on a relative scale based on wet or damp materials having a higher capacity than dry materials [6].

Figure 1b show moisture content in wooden constructions measured with two-pin moisture meter. The average measured moisture content in wooden constructions is 9.5 weight-% in representative areas corresponding to about 40% RH and in most cases it is between 8 and 12 weight-%. The average measured moisture content in moist areas is 12 weight-%, with a standard deviation two times higher than in representative areas. Moisture content in other materials was measured with a capacitive moisture meter. The average value, expressed as counts, is higher in visible moist areas than in representative areas: In materials with low density (gypsum or plastering on reed mesh) the average value is 13 in representative areas and 35 in moist areas; in materials with high density (brick or concrete) it is 16 and 43, respectively. Further, the standard deviation is 3-4 times higher in moist areas.

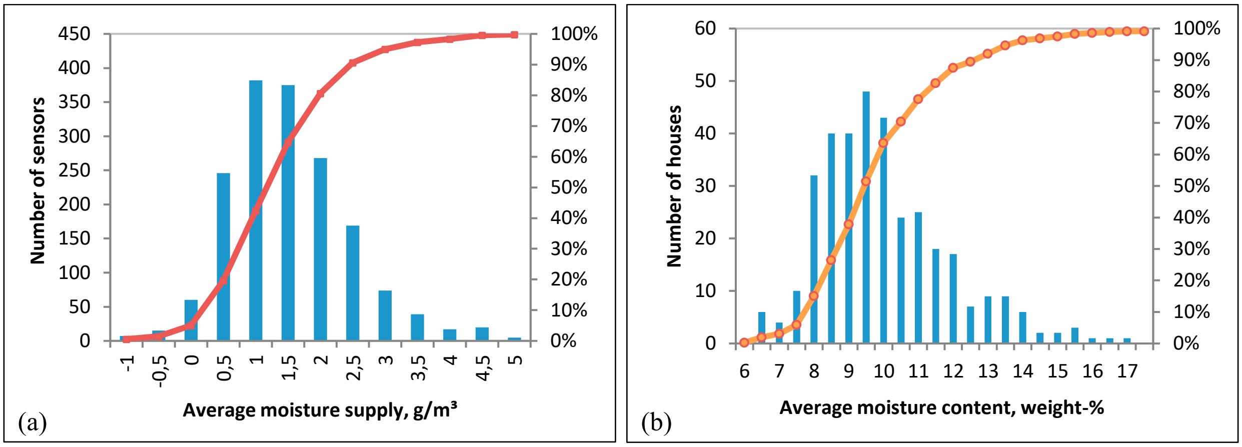



Figure 1. (a) Distribution of moisture supply (g/m$^3$) based on single sensor measurements of relative humidity and temperature located in different rooms. (b) Distribution of average moisture content in representative areas (weight-% in wood) of houses using two-pin moisture meter. Histogram (columns; number of sensors (a) and houses (b)) and cumulative curve (%). All types of buildings and rooms.

## 4. Discussion

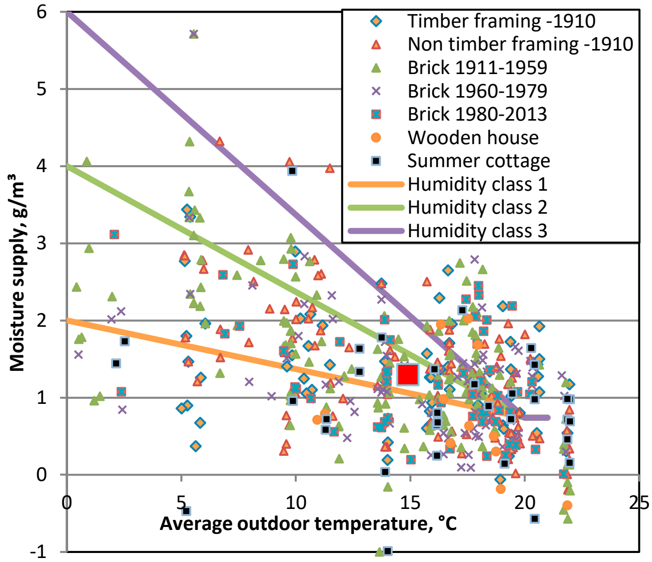
*4.1. Moisture supply and internal humidity classes*

Danish single-family houses are assumed to belong to humidity class (HC) 2, which is given in [3], based on interrelated values of moisture supply and outdoor temperature. Figure 2 shows that in many cases moisture supply in a house is either higher or lower than it would be if belonging to HC 2. In many cases average outdoor temperature is 15 °C or higher, where upper limits between the different humidity classes are closing in. Consequently, the assessment of which HC a house belongs to is more sensitive to the precision of measurements and variations in the indoor climate. Humidity class assessment of houses investigated at outdoor temperatures below 20 °C, showed that 40 % belong to HC 1, 28 % to HC 2, and 32 % to HC 3 or higher. Especially the many cases with a moisture supply higher than HC 2 need to be taken into account, as the moisture load will be underestimated if HC 2 is used as reference. A relation between moisture supply and outdoor temperature is seen; the higher the outdoor temperature the lower the moisture supply, but the spread is high (coefficient of correlation is 0.5). An explanation could be that occupants probably open windows more often at high outdoor temperatures.

*4.2. Dependency of type of building*

Figure 2 also shows the relation between moisture supply and outdoor temperature when the houses are divided in building types. There seems to be no connection between moisture supply and type of building, but this is complicated by the fact that many of the results are concentrated at high outdoor temperatures where the upper limits of the different internal humidity classes are getting quite close to each other. By performing t-tests on a 5 % level assuming that the average value of moisture supply follows a normal distribution for each type of building, it is shown that differences between types of building is coincident (marked green in Table 1), except for wooden houses and in some cases for summer cottages, where the moisture supply is significantly lower (marked red in Table 1). Surprisingly, different moisture supply in two types of houses after 1910 is not coincident either. In general, the hypothesis that in many cases two building types have the same moisture supply cannot be rejected, meaning that in future studies the building stock can be divided in fewer building types.

t-tests on the type of ventilation, mechanical or natural, showed that differences were coincident, although moisture supply tended to be lower in houses with some kind of mechanical ventilation, e,g. an exhaust hood.




| | Timber framing -1910 | Non timber framing -1910 | Brick 1911-1959 | Brick 1960-1979 | Brick 1980-2013 | Wooden house |
|---|---|---|---|---|---|---|
| Non timber framing -1910 | | | | | | |
| Brick 1911-1959 | | | | | | |
| Brick 1960-1979 | | | | | | |
| Brick 1980-2013 | | | | | | |
| Wooden house | | | | | | |
| Summer cottage | | | | | | |

Figure 2 (left). Average moisture supply for each specific house – divided after type of building – and average outdoor temperature in the time period of measurement (symbols). Average for all houses (red square). Straight lines = upper limit of internal humidity classes according to [3].

Table 1 (right). Overview of in which cases differences in average moisture supply between types of buildings are significant (marked red) or not (marked green), based on t-tests on a 5 % level.

*4.3. Dependency of geography*

The municipalities included in the study were selected to ensure a geographical representation. Figure 3 is based on the assumption that a linear relation exists between moisture supply and outdoor temperature, which can be questioned cf. Figure 2. In Figure 3 it is marked how much the average moisture supply for houses in a specific municipality deviates from this linear relation. Moisture supply above average is marked blue and moisture supply below average is marked orange. Geographical differences can be observed, e.g. it seems that the measured moisture supply is lower than the calculated in North and East and higher in West and South, although this distinction is not covering all the included municipalities, e.g. the municipality with the highest orange column.

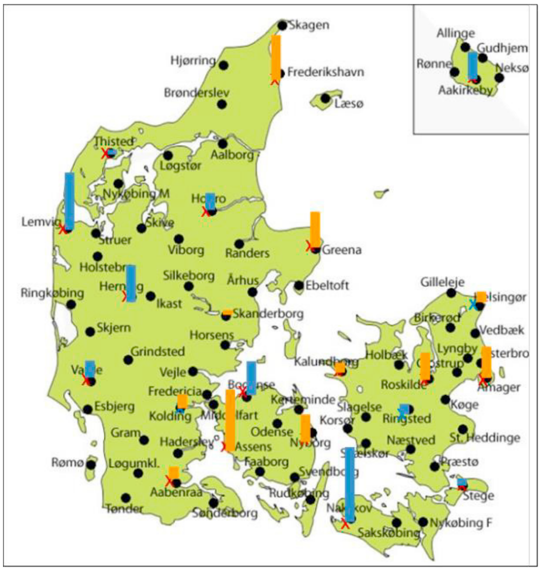



Figure 3. Differences in measured and calculated moisture supply for each of the 21 Danish municipalities included in the study. Calculated moisture supply is based on an assumption of a linear relation between moisture supply and outdoor temperature. Columns represent differences between measured and calculated moisture supply; blue when measured value is higher, orange when lower than calculated moisture supply. The higher the column the larger the difference.

Further there does not seem to be any correlation within the groups, e.g. that the columns get higher or lower the more Northern the municipality is situated. Neither can a relation between measured moisture supply and distance to the coast be seen, which would relate to the differences in climate between coastal areas and more inland areas [7]. Therefore, there is no simple way to divide Denmark in different “moisture zones”, instead the whole country should be treated as a single zone, but with large variations.

### *4.4. Measurements in air vs measurements in material*

Figure 4 show interrelated values of moisture content in wood by two-pin measure meter, and indoor air relative humidity in the same room, having a coefficient of correlation of 0.24. The low correlation is supported by Figure 1b; average moisture content in wood of 9.5 weight-% is lower than expected based on measurements of relative humidity. The low correlation is surprising; normally measurements of moisture in wood are considered to be valid, although instruments may have an uncertainty up to 10%. The relative humidity was between 35% RH and 70% RH, in this interval wood has some moisture capacity and the sorption curve is almost a straight line with a slope, as shown in Figure 4. It is less surprising that measurements with capacitive moisture meter had no correlation with relative humidity (e.g. 0.04 for low-density materials), as the materials included in these measurements have very low moisture capacity. The sorption curve is therefore almost horizontal, making uncertainties in instruments more critical.

One of the reasons for measuring moisture in materials was that moisture content in the air of a building can easily be manipulated simply by opening all windows and then turn up the heating, which in case of a building inspection will blur the picture of the real moisture supply under normal conditions. As materials react slower, they could be seen as the memory of the house, revealing if the moisture load normally is high. However the results do not support this idea. One explanation could be that the snapshot measurements in materials were performed just before the logging of hygrothermal data was started. Consequently material moisture was a result of the moisture load earlier than the measurements in the air. Nevertheless, materials act slowly and the occupants had no reason to change their behavior during the time where the loggers were in place; they had all agreed on participating in a research program where no one would get results from a specific house. It is therefore questionable if the result would have been much different, if material measurements were made after the period with air measurements.

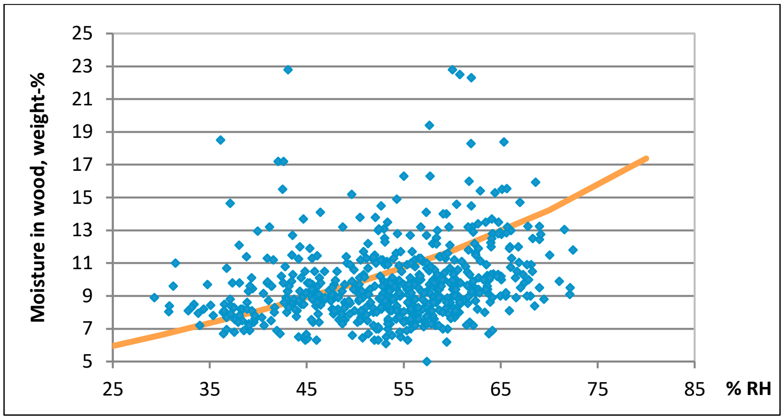



Figure 4. Moisture in wood in weight-% using two-pin measure meter compared with measurements of indoor air relative humidity in the same room (average values for a 14 day period). Curve represents sorption curve for wood.

## 5. Conclusion

A very high spread in moisture supply should be expected for Danish single-family houses; 32 % were in humidity class 3 or above and 40 % were in humidity class 1; i.e. in many cases simulations based on humidity class 2 will under- or overestimate the moisture load.

The building type had only limited effect on the moisture supply, primarily related to lower values in wooden houses and summer cottages. The ventilation had no significant effect either. The geographical location had an effect on the moisture supply, however no systematic dependency of geography could be found. It is recommended to regard Denmark as a single moisture zone and accepting large variations.

It is not possible by means of snapshot measurements using two-pin moisture meter in wooden construction or capacitive meters in other materials to estimate the indoor relative humidity in single-family houses; i.e. making such measurements as a part of a one-visit building investigation will not make it possible to estimate the normal moisture supply.

## Acknowledgements

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