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Risk Assessment Model Applied on Building Physics: Statistical Data Acquisition and Stochastic Modeling of Indoor Moisture Supply in Swedish Multi-family Dwellings

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ABSTRACT

Though it is highly appreciated and asked for by the practitioners there is a lack of tools to perform proper risk assessment and risk management procedures in the area of building physics. Many of the influential variables, such as outdoor temperature and indoor moisture supply, have stochastic variations, thus a general approach for risk assessment is complicated. The aim of this study is to define risk concepts in building physics and develop a risk assessment model to be used in the field. The study is based on hazard identification tools used in process industry, such as What-if, HAZOP, FMEA and VMEA. The tools are compared and used in the modeling process which leads to identification of noise factors during design, construction and service life. A literature survey is conducted in order to find statistical input data that should be used in the applicability study, based on stochastic simulations and air flow path modeling in CONTAM. By combining the hazards and safeguards in a scenario, together with Monte Carlo simulations, gives results with a distribution, dependent on the variability of the noise factors. The applicability study shows good correspondence with measurements performed on the indoor moisture supply in Swedish multi-family dwellings. Risk and safe scenarios are defined by comparing the result of the scenario with an allowed level of consequences. By implementing risk management into building physics design, it is possible to indentify critical points to avoid extra unwanted costs. In addition, risks concerning indoor climate, health and durability are clarified.

KEYWORDS

Risk assessment model, hazard identification, stochastic variations, building physics

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1 INTRODUCTION

The European Union has agreed to reduce its greenhouse gas emissions by 20% from 1990 to 2020 and up to 30% with an international agreement. Since the energy used in buildings account for 40% of the total final energy use, a large part of the existing buildings in the EU need measures of thermal retrofitting to reach the target (European Commission. 2008). This may result in an increased insulation thickness in the building envelope, which might lead to problems with moisture damages in the buildings (Pallin, S. 2010) The Swedish National Board of Housing, Building and Planning estimates that approximately 66% of all Swedish buildings are damaged in some way. 45% of the damages that have been discovered happen because of moisture damages; mostly in crawl and attic spaces. The moisture damages might affect the durability and the indoor climate of the buildings (Boverket. 2009).

During the construction phase of a typical Swedish building project 4.4% of the total project cost and 7.1% of the project time is devoted to correct mistakes which have been taken place during the construction (Josephson, P-E. & Hammarlund, Y. 1996). Taking the probability of undetected failures into account in the design phase of a building project would save money and make the buildings more resistant to problems and damages during service life. According to Josephson and Saukkoriipi (2005) the potential reduction of building costs is up to 50% if all mistakes and time waste during construction could be removed. Early identification of hazards which can cause failure is important if the mistakes should be minimized. This procedure would reduce the discomfort of the occupants and the potential decreased reputation of the contractors. Also the costs for the building industry when correcting failures would decrease heavily as the building gets more durable.

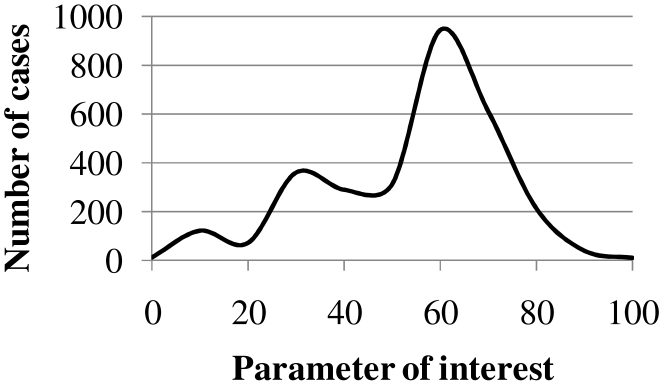

Figure 1–1 The distribution of the studied parameter has to be taken into consideration when performing a risk analysis. Example of a frequency curve from a large number of observations.

This study aims to develop a risk assessment model and tool which can be used during the design process in order to reduce the vulnerability of failures in the construction and minimize the effects of failures. The model is based on hazard identification and risk assessment with consideration to the building's lifetime. Buildings are complex systems where the use of deterministic data limits the possibilities to make simulations for a proper risk analysis. A large part of the parameters varies stochastically which demands data produced during stochastic conditions. Figure 1–1 shows an example of how a parameter may vary when performing a large number of simulations. The impact of influencing parameters such as weather, building materials, indoor moisture sources and ventilation can be studied using stochastic data in the simulation. By using this procedure, the most varying hazardous elements can be identified and measures may be taken in order to reduce their effect. The study is limited to only consider important aspects of indoor moisture supply when performing retrofitting of existing buildings, although the model should also be applicable on new construction projects. The moisture buffer capacity of the surrounding indoor materials effects the variation of the indoor moisture supply over time. This aspect will not be considered since the levels of indoor moisture supply retrieved by the Monte Carlo simulations are to be administered with a HAM-tool where such influence should be taken into consideration.

2 METHOD

The hazards when considering indoor air humidity are presented as moisture sources i.e. activities which increase the moisture content of the indoor air. These hazards are governed by a number of noise factors which by definition have variable influence. For each given noise factor, a distribution of plausible values and their effect must be established if realistic values of the hazard are to be estimated. The noise factors are considered to have stochastic variations and therefore Monte Carlo simulations are suitable for the simulation of each specific hazard. An example of a hazard when speaking of indoor moisture supply is the activity of taking a shower. The main subsequent noise factors are the water temperature, the water vapor pressure and indoor air dew point temperature together with the duration and time of the activity.

When the probability distribution curve of the moisture production is defined for each hazard, the presented method requires that the user behavior of the members of the household must be coupled to the hazard. A computer program controls statistical data and simulates the probability of a hazard to occur. The program facilitates the assembly of all the hazards into the variations of total indoor moisture production over time. In this study the risk assessment program @Risk is used to satisfy the previously defined conditions. @Risk is used in order to simulate the variations of the given moisture sources based on defined inputs. Each input will make the simulations more precise; thus narrowing the spreading and increasing the accuracy of the results. Consequently the result depends upon the set of statistical data which are used in the simulation model. Type of accommodation, number of persons in the household and the residential floor area are all examples of inputs which are used to administer the statistical data.

An applicability study is performed in order to test the developed risk assessment method. Specific conditions of the retrofitting case is used as input data in @Risk and simulations of different household compositions and levels of moisture production is performed. The air flow rates between the different zones of the studied reference object are obtained by performing simulations in CONTAM. Stochastic variations of the indoor moisture supply is obtained by combining the results from @Risk and the results from making simulations of indoor air exchange of the reference object.

3 RISK MODELLING

To be able to create a risk assessment model for this study, one has to define the system structure and system behavior, but also the standards and targets that the system outcome should fulfill. Information is needed on how the parts of the system are put together and how the system develops over time. Basically the model should be a representative of reality, broken down in manageable pieces which each describe a part of the system behavior. When the model is put in place, simulations can be performed to study the outcome when different parts of the system are changed and also to increase the knowledge on how the system parts interact.

When the system has been defined, the first phase of the risk modeling process is to identify the hazards by creating scenarios that can lead to system failure. There are numerous hazard identification tools developed, such as what-if, HAZOP, FMEA and VMEA. The outcome when using one of these tools is possible scenarios, or failure modes, that can lead to loss or damage. The scenarios might need to be validated, for instance by the opinion of experts in the studied field, in order to reduce the uncertainties and also to ensure that all major and credible scenarios have been targeted. Each of the scenarios are then connected to a probability for a consequence and then the probability can be evaluated and compared with acceptable level of loss or damage as specified by targets or standards. If the risk is higher than what is an acceptable level, measures may have to be taken in order to lower the risk for that scenario to occur.

4 HAZARD IDENTIFICATION TOOL COMPARISONS

The first method discussed is the what-if method, which analyses the consequences of different scenarios based on a brainstorming process performed by an experienced expert team. The results from the what-if analysis usually suggest solutions to specific hazards (Shahriari, M. 2010). Questions asked during the process for building physics might be of the type “What if the indoor moisture supply in the building reaches critical levels?”. The consequences and recommendations from creating scenarios are based on the knowledge and experience of the expert team. Since it is crucial not to omit major problems, and the method is based on good understanding of the system at hand, an experienced expert team is required (Davidsson, G. *et al.* 2003).

HAZOP, HAZard and OPerability study, is another tool for hazard identification which was developed for the processing industry. The method is composed of a detailed review of a system for identifying possible hazards, failures and operability problems. This method requires a team of experienced experts who discuss every part of the system with help of different guidewords that describe different parameters which can deviate from normal operation. The purpose of the HAZOP is not primarily to solve potential problems, but to identify possible problems (Davidsson, G. *et al.* 2003).

Another method that can be used in building physics to analyze risks is the FMEA (Failure Modes and Effects Analysis). The method evaluates the way equipment can fail and the effects these failures can create on the system. Each individual failure is considered to be an independent event with no connection to other parts of the system, except for failures caused by the original failure. The FMEA identifies single failure modes in the system and determines the consequences the failure might cause on a small scale and on the system as a whole. A grading system is used to find the worst failure modes and effects, for which recommended solutions are proposed (Shahriari M. 2010). Nielsen (2002) used FMEA on moisture problems in buildings with the three failure modes “liquid water in the building”, “surface condensation” and “internal condensation in the structure”. The failure modes are then subdivided down to a fifth level due to the reason of finding the root cause of the failure modes. Nielsen finds it to be a seldom case that the root causes are found and that we often are able to go more into detail with the causes, something that proves to be very time consuming.

A recently introduced hazard identification method is the VMEA (Variation Mode and Effect Analysis). Instead of concentrating on failure modes, the VMEA method looks for noise factors with excessive variation, affecting the system outcome. The goal of the analysis is to find and rank noise factors that have effect on the variation of the final product. By conducting four steps in the VMEA, done by an experienced team, a VRPN (Variation Risk Priority Number) is calculated for the noise factors, ranking the most influential noise factors highest (Chakhunashvili, A. *et al.* 2004). The coming chapters deal with hazards connected to the moisture durability of a building and starts with an identification of the major hazards associated with the indoor moisture production. The chosen process deals with identification of hazards and noise factors and the goal is to take these variations into account in heat, air and moisture simulations of whole buildings and building parts.

5 DEFINITION OF RISK

There is a difference between the definitions of reliability and risk which can be found in the field of reliability engineering. Kaplan and Garrick (1981) discuss risk as something involving both uncertainty and some kind of received loss or damage. According to this definition, risk is an uncertainty connected to a bad consequence that should be avoided and that risk would need some kind of quantified consequence that gives a percentage or level for how large the risk is compared to other risks. Haldar and Mahadevan (2000) define reliability as the probability of a process to successfully satisfy some performance criteria and risk as a measure of the probability of failure, hence risk and reliability are complementary terms. This way of describing risk and reliability is not possible in the field of building physics since there is always a risk of failure. The part of a consequence not leading to failure is called a safe consequence, see Figure 5–1. A safe consequence is not necessarily part of a reliable system, based on the previously described definitions of risk and reliability. Therefore it is hard to further develop reliability models in building physics. In this paper risky and safe consequences are separated by some grading of the scenario's consequence, compared to the allowed consequence.

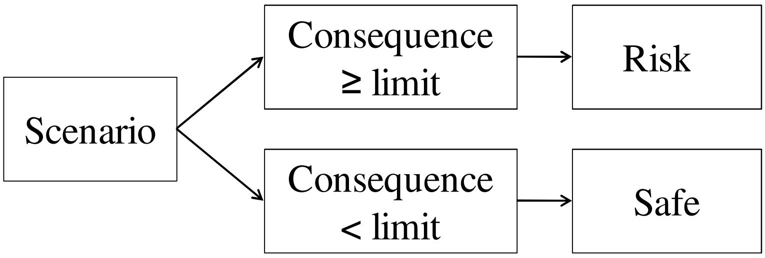

Figure 5–1 A scenario can lead to a defined consequence which together develop the risk of the defined consequence to occur. Consequently, the safe consequence is obtained as the residual value due to the probability of the risk. The consequence evaluation can be based on design standards or expert's opinions.

There are some basic components that have to be defined in order to discuss the concept of risk. The noise factors in this paper are considered to be the lowest level of influential parameters in the risk assessment model. They influence the outcome of different events or activities that hereafter are called hazards and safeguards, see Figure 5-2. Hazard is a potential energy; a condition or source of danger that have the potential of resulting in some kind of event; mold growth in the bathroom or condensation in an exterior wall. Risk is defined as the probability that a scenario composed of a number of different hazards will cause failure or damage to the system. Therefore hazard is the source of a potentially dangerous event and risk is connected to the probability of that event leading to loss or damage. It is possible to use safeguards in order to reduce the risk for a hazard to develop into a loss, but it is not possible to make the risk zero. Awareness of a hazard means that safeguards can be put in place to minimize the risk, thus awareness of risk reduces risk (Kaplan, S. & Garrick, B.J. 1981). When discussing moisture production in a building, the hazards are for instance bathing, food preparation and drying of laundry and the safeguards that can reduce the risk are e.g. ventilation and air dehumidification.

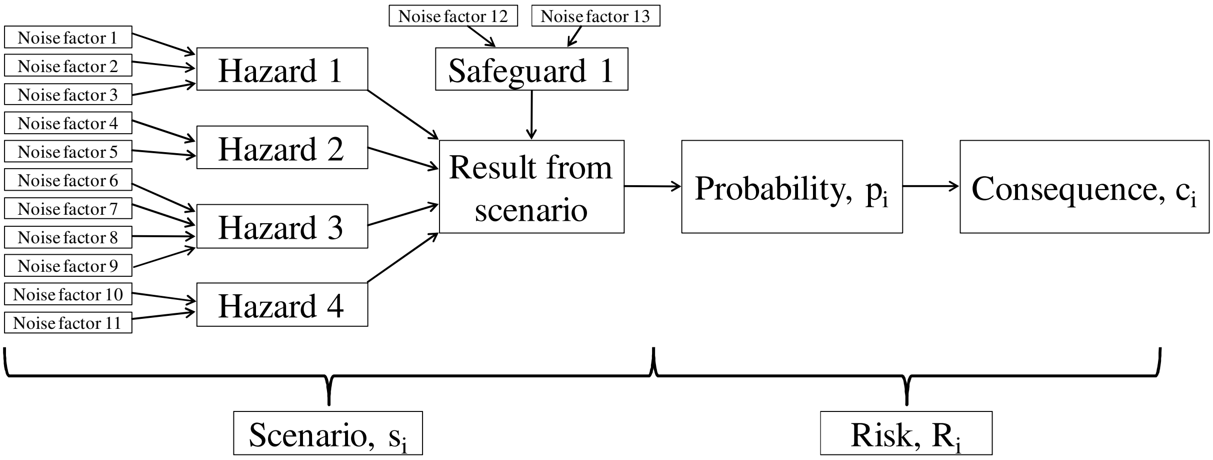

Figure 5-2 Risk model with a scenario sample, s_i, composed of a number of hazards and safeguards. The noise factors influences the hazards and safeguards which define the distribution of the result. The consequence, c_i, and probability, p_i, are based on the results from the scenario which altogether give the risk, R_i.

The Greek word "stochos" means uncertain and create the base of the word stochastic, which means a random process (Haldar, A. & Mahadevan, S. 2000). Most engineering tasks involve some degree of stochastic variables that influence the outcome of a given problem, e.g. the number of occupants in a randomly chosen apartment will influence the moisture production in that apartment. Another example is measurements which will give different results due to different test specimens, caused by stochastic variations of the physical properties of the test specimen and natural dysfunctions of the measuring device. These variations are here called noise factors which are defined as variations that cannot be controlled, or are very difficult to control. When designing a system it is crucial to take the noise factors into account in order to design a system free of unwanted events.

It is important to consider different hazards and safeguards together with defined scenarios, potentially leading to unwanted consequences. Risk is then the probability of a defined scenario to result in a specified consequence. Kaplan and Garrick (1981) discuss this matter as the "Set of Triplets Idea" which can be described by the following Equation:

$$R_i = f(s_i, p_i, c_i) \qquad i = 1,2,\dots,n \tag{5-1}$$

where R_i is the risk of a scenario sample, s_i is the scenario sample, which have to be a subset of the whole scenario, p_i is the probability of the sample leading to c_i, the consequence of the sample. i is the scenario sample number from 1 to n. In order to calculate the total risk for a specified consequence, the risk for all scenario samples leading to that consequence should be added:

$$R_{tot} = \sum_{i=1}^{n} R_i \tag{5-2}$$

All noise factors influencing the hazards and safeguards in a scenario have to be identified in order to obtain the probability of a consequence. An increasing number of noise factors, or noise factors with large variations, create a larger spread in the variation of the consequence of the hazards and safeguards, as described in Figure 5–3. Consequently, a more wide shape of a distribution demands a larger number of values in order to estimate the risk, compared to a hazard or safeguard involving less noise factors.

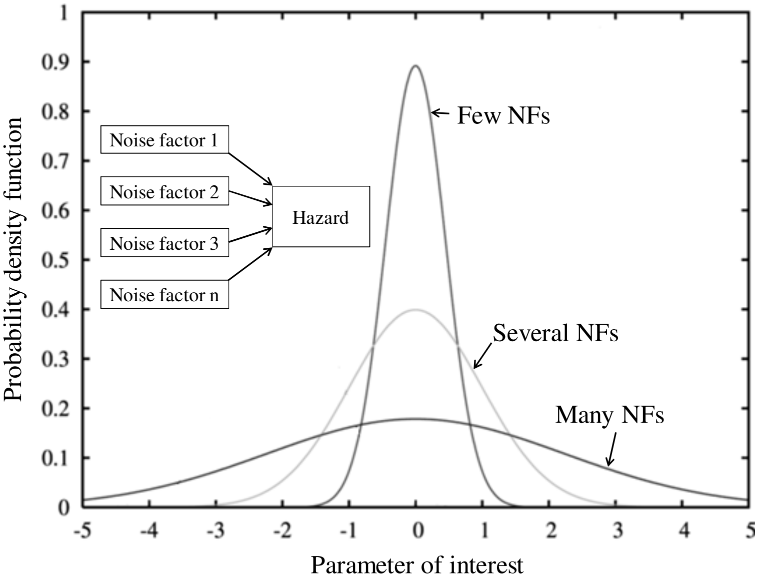

Figure 5–3 A larger number of noise factors, with equal influence, result in a larger spread of the distribution of the hazard or safeguard. Therefore a less number of noise factors result in a more narrow distribution.

6 HAZARDS, SAFEGUARDS AND NOISE FACTORS IN BUILDING PHYSICS

The field of building physics involves many hazards that can result in scenarios ending in unwanted consequences for the building owner and occupants. Some of the hazards and safeguards are outdoor climate, indoor moisture production, indoor heat supply, material and surface properties, air tightness and air exchange rate, see Figure 6–1. Except for the outdoor climate, these parameters are usually included when simulating transient heat, air and moisture transfer, without considering the deviations caused by stochastic variations. During the hazard identification process, the main scenarios leading to an unwanted consequence are presented and evaluated in order to identify the most decisive hazards. There is a difficulty involved in the identification of all hazards in the aspects of risk and probability for the scenarios to occur, since the underlying hazards depend on a large number of noise factors. Examples of the scenarios and consequences in building physics are household equipment which has been used in a bad way leading to failure (water leakage), the relative humidity in a building part exceeds the critical levels of mold growth initiation or a material fails to satisfy expected level of thermal resistance.

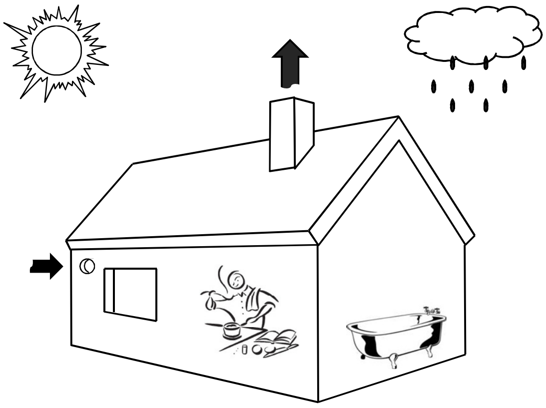

Figure 6–1 Schematic figure of the hazards and safeguards which have to be taken into consideration in the risk assessment model; climate, indoor heat and moisture production, material and surface properties and ventilation.

The number of noise factors and hazards influencing the final simulation grows rapidly and therefore the risk assessment model is not adapted for hand calculations. Because of the large number of noise factors affecting the system, the use of computer software is recommended. In the applicability study Monte Carlo simulations are performed in the Microsoft Excel add-in @Risk in order to produce a distribution of the indoor moisture production based on stochastic variations.

@Risk simulates the probability distributions of the hazards when considering indoor moisture production. These distributions depend on the variations of the pertaining noise factors. Figure 6–2 presents an example on how the hazards affect the final risk of a defined consequence. If considering the indoor moisture supply in a bathroom, some of the hazards are the indoor moisture sources from bathing, showering, laundry appliances and floor mopping. The ventilation system is considered as a safeguard which by definition decreases the influences of the moisture sources. Consequently, the probability distribution of a consequence will be the result of the conditions defined by the scenario. In Figure 6–2, a risk assessment scenario is created to simulate the variations of indoor moisture production in a bathroom in Swedish multi-family dwellings. The outcome of the scenario is the probability of either a safe or an unwanted consequence, whereas the latter is defined as the risk.

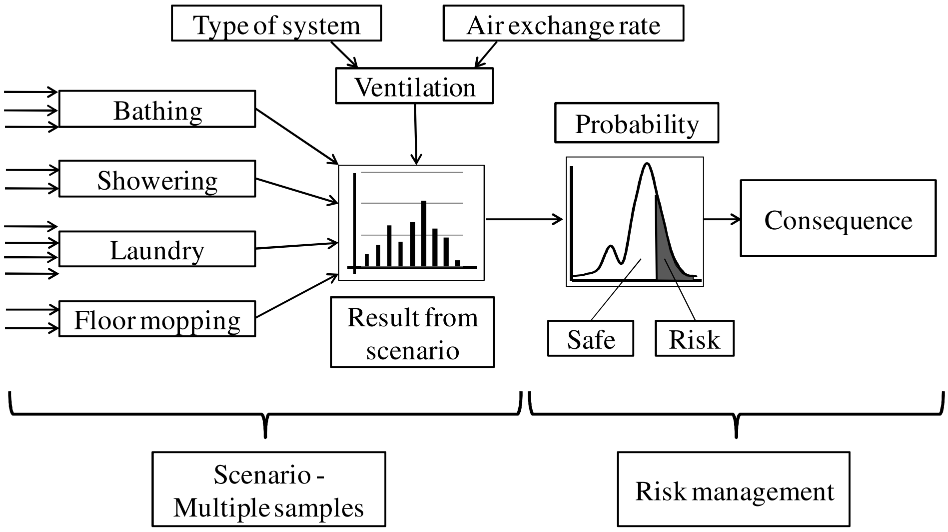

Figure 6–2. Example of the risk assessment model when studying a scenario of the indoor moisture supply in a bathroom with the associated hazards bathing, showering, laundry appliances, floor mopping and the safeguard ventilation.

7 INDOOR MOISTURE SOURCES

When predicting the total level of indoor moisture supply, rates of moisture generation from various moisture sources, also referred to as moisture loads, are essential inputs (Yik, F.W.H. *et al.* 2004). To be able to estimate the total daily moisture load, the incident frequencies are needed (Christian, J.E. 1994). The moisture loads will also vary on weekly basis due to the variations of user behavior of the residents during weekdays and weekends. It is also important to define variations for longer period of time since seasonal variations could be expected (Kalamees, T. *et al.* 2006).

In order to identify realistic and useful properties for each moisture source i.e. the hazard in consideration, a general model will be defined. The model serves as a template when identifying and assembling the noise factors and their variations over time.

Three major noise factors of concern for the model are the following.

- Time – The precise time for the occurrence of a specified event i.e. at what time the moisture source initiate.
- Duration – How long period of time the moisture source will proceed.
- Level – The rate of moisture generation. What levels of moisture production are expected for each source and what are the supposed variances.

In addition to the noise factors above, other occasional factors might also influence the distribution depending on the hazard i.e. the specific moisture source. Several of the specified moisture sources are not present in every household. Therefore a weighted distribution is required, referred to as the incidence factor, I_f. Also correlations between different noise factors might be relevant in order to define a complete distribution of the moisture production over time.

A declaration for each hazard when considering indoor moisture source will be presented shortly with the aspect to the previously discussed template of noise factors. The definitions of the given factors will be based on surveys and experiments made in the area of building physics as well as information given by manufactures. Information regarding the occurrence and the duration of an event are usually received from statistical departments and organizations. If possible, statistics based on the Swedish households will be used. If no such data exists statistics from countries with similar standard of living and housing types will preferably be used. Qualified assumptions will take place in the areas where little or no knowledge is found. The purpose of this approach is to, despite the lack of sufficient knowledge, still be able to produce an arbitrary simulation model of the total indoor moisture production.

7.1 Bathing

The time probability for bathing will be based on a residential survey regarding energy behavior in 600 Swedish households (Carlsson-Kanyama, A. *et al.* 2003) together with the probabilistic distribution of hygienic activities in Swedish household (HETUS. 2005-2007).

Table 7-1 Time probability for bathing for each member of the household in Sweden (Carlsson-Kanyama, A. et al. 2003).

Time probability - Bathtub	[%]
More than once per day	1.0
Once per day	3.6
4 to 6 times per week	10.0
1 to 3 times per week	27.0
less than once per week	58.0
No response	0.4

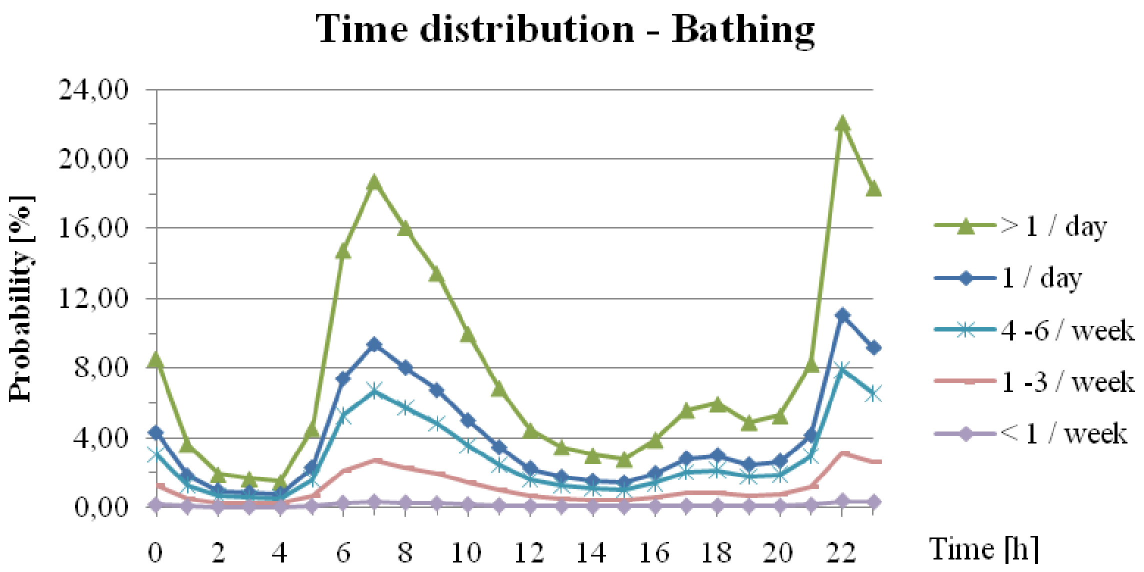

Figure 7–1 Time distribution for each probability regarding bathing behavior. The shape of the curves corresponds to hygienic activity in Swedish households (HETUS 2005-2007).

The duration for bathing varies slightly according to the information found. A reasonable average time for bathing varies between 15 minutes (Christian, J.E. 1994) and 18 minutes (Yik, F.W.H. *et al.* 2004). These average values for the duration of a bath in a bath tub correspond well with the information given by a Japanese study (Takaaze, A. 2007), see Table 7-2.

Table 7-2 Duration for the activity of bathing with seasonal variations regarding mean, maximum and minimum values together with standard deviations (Takaaze, A. 2007).

Duration for bathing in bath tub [min]											
Summer				Autumn				Winter			
μ	σ	max	min	μ	σ	max	min	μ	σ	max	min
12:49	04:48	21:25	04:17	16:50	05:53	28:48	05:22	11:33	04:50	24:16	06:02

The level of moisture generation from bathing will be greatly influenced by the area of exposed water, the saturation vapor pressure at the water surface and the saturation vapor pressure at room air dew point temperature (ASHRAE. 2007). The area of a residential bath tub is assumed to differ slightly hence a good estimation would be a variation between 0.7 to 1.1 m^2 (Ifö/Products. 2010a). The saturation vapor pressure at the water surface is in direct relation with the temperature of the water surface. A Japanese study on bathing behavior for elderly (Takaaze, A. *et al.* 2007), reveals probable water temperatures for bathing in accordance with Table 7-3.

Table 7-3 Water temperatures for bathing with seasonal variations regarding mean, maximum and minimum values together with standard deviations (Takaaze, A. 2007).

Water temperature for bathing [°C]											
Summer				Autumn				Winter			
μ	σ	max	min	μ	σ	max	min	μ	σ	max	min
41.1	2.5	43.7	35.2	41.0	1.7	43.8	37.8	41.2	1.7	43.0	38.4

The saturation vapor pressure at room air dew point temperature is not only dependent on the temperature of the indoor air but also the indoor air humidity. To be able to make a good assumption of the indoor environment, the indoor relative humidity can be estimated using EN 15026 where the indoor relative humidity is assumed 30% at a -10°C outdoor temperature and 60% at a 20°C outdoor temperature. There is a linear variation of the relative humidity between these temperatures and fixed values above and below.

Table 7-4 The saturation vapor pressure at different water surface temperatures are presented at the left-hand side of the table. The partial water vapor pressure at different relative humidity and indoor temperatures are presented to the right.

Water temperature [°C]	**p_w [kPa]**	**Air temperature [°C]**	**p_a [kPa]**				
			30%	40%	50%	60%	70%
35.0	5.629	17.0	0.581	0.775	0.969	1.163	1.357
35.5	5.788	17.5	0.600	0.801	1.001	1.201	1.401
36.0	5.948	18.0	0.619	0.826	1.032	1.239	1.445
36.5	6.115	18.5	0.639	0.853	1.066	1.279	1.492
37.0	6.282	19.0	0.659	0.879	1.099	1.319	1.539
37.5	6.457	19.5	0.681	0.907	1.134	1.361	1.588
38.0	6.632	20.0	0.702	0.936	1.170	1.404	1.637
38.5	6.816	20.5	0.724	0.965	1.207	1.448	1.690
39.0	7.000	21.0	0.746	0.995	1.244	1.493	1.742
39.5	7.192	21.5	0.770	1.027	1.283	1.540	1.797
40.0	7.384	22.0	0.794	1.058	1.323	1.587	1.852
40.5	7.586	22.5	0.818	1.091	1.364	1.637	1.910
41.0	7.787	23.0	0.843	1.124	1.405	1.687	1.968
41.5	7.998	23.5	0.869	1.159	1.449	1.739	2.029
42.0	8.209	24.0	0.896	1.194	1.493	1.791	2.090
42.5	8.430	24.5	0.923	1.231	1.539	1.847	2.154
43.0	8.650	25.0	0.951	1.268	1.585	1.902	2.219
43.5	8.881	25.5	0.980	1.307	1.633	1.960	2.287
44.0	9.112	26.0	1.009	1.345	1.682	2.018	2.355

Finally the water evaporation rate from a bath tub can be calculated using the approximation given by the following Equation (ASHRAE. 2007):

$$w_p = 0.144 \cdot A \cdot (p_w - p_a) \cdot F_a \tag{7-1}$$

where w_p is the evaporation of water [kg/h], A is the area of the exposed water surface [m^2], p_w is the saturation vapor pressure at water surface temperature [kPa], p_a is the saturation vapor pressure at room air dew point temperature [kPa] and F_a is the typical activity factor. The water surface will evaporate differently due to different level of movement at the water surface. For residential bathing in a bathtub this factor is considered to be 0.5 (ASHRAE. 2007).

It is of great importance to adjust the given probability for bathing with an Incidence factor i.e. the probability of a household to be equipped with a bath tub. The mean Incidence factor, I_f for bathing comprising all Swedish households is 67% (Carlsson-Kanyama, A. *et al.* 2003).

7.2 Showering

The user behavior for showering has not been found, which may be considered suitable for Swedish households. Usually such activities as taking a shower are subcategorized into “Other personal care” (SCB. 2003) or “Grooming” (BLS. 2009). Once the original data from a survey is logged, this type of sub-division generally disables the possibility to reveal the specific activities afterwards (Molén, M. 2010).

An activity pattern survey of Californian residents made between the period of October 17, 1987 until October 6, 1988 reveals useful information (Air Resources Board of the State of California. 1990). 1,762 persons in 1,579 households were interview by The Survey Research Center at the University of California, Berkeley. The raw-data from this survey is still accessible and of great use since it is still uncategorized. The time of showering and the mean distribution during the period of one day is given by Table 7-5.

Table 7-5 The time distribution for showering according to an activity pattern survey of Californian residents in 1988 (Air Resources Board of the State of California. 1990).

Probability for showering during 24 hours. [%]											
00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00
0.23	0.23	0.26	0.29	1.25	4.82	9.59	11.65	8.31	6.25	4.85	3.17
12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
2.21	1.54	1.54	1.95	3.02	4.39	6.22	10.14	8.43	5.14	3.05	1.37

According to data from the survey I_f is equal to 85.11% for showering. This means that on a daily basis there is a probability of approximately 85% that each member of a household takes a shower. Since the time distribution is based on a warmer climate compared to Sweden this factor might have to be adjusted. For this study an assumption is made that an I_f of 50% is more suitable for the Swedish household during the winter, hence a seasonal variation between winter and summer of 50% and 85% will be assumed.

As for bathing the water vapor production during a shower is in relation with the duration of the activity. The estimated duration for showering varies between five and fifteen minutes (Christian, J.E. 1993). Usually a shower is assumed to last for five minutes hence the moisture generation during a shower is expressed in the way of a total moisture production instead of a production rate (Hansen, A.T. 1984; Angell, W.J. & Olson, W.W. 1988; Rousseau, M.Z. 1984; Kalamees T. *et al*. 2006).

Table 7-6 Estimated moisture production from taking a shower.

Moisture generation from showering [kg / 5min]					
Angell W.J. 1988	*Christian J. E. 1994*	*CIBSE 1999*	*Hansen A.T. 1984*	*Rousseau M. 1984.*	*Kalamees T. 2006*
0.25	0.22	0.20-0.38	0.23	0.35	0.30

In this study, when making simulations, the moisture production when showering are assumed to vary between the values given in Table 7-6 and the previously described model for seasonal variations.

7.3 Sauna bathing

Very little information is found regarding the time distribution of using the Sauna. The same problem exists with sub-division of logged activities as explained in Chapter 7.2. The sub-division is a result of the statistical coders with the intention of handling the data more easily, thus it is not possible to identify the frequency of using the Sauna from most statistic surveys (Reifschneider, M. 2010).

The activity of Sauna bathing probably requires a time distribution with seasonal variations. An assumption may be that the frequency of usage will increase during the heating season. Consequently the time distribution for the activity of Sauna bathing in Sweden is still to be investigated and time distributions must be assumed in order to establish a moisture generation model for this activity.

The frequent user practices Sauna bathing several times a week (Spolander, S. 2010). There is also a great difference in user behavior depending on the location of the dwelling. The Sauna is much more common in the northern parts of Sweden in correlation with a much more frequent usage.

According to an investigation and survey of technical features in Swedish residences, about 4% of the multi-family dwellings in Sweden are equipped with a Sauna unit (Tolstoy, N. *et al.* 1993). On average the unit is used 4 hours per week. The investigation reveals that there are 2 million apartments in Swedish multi-family buildings and the number of buildings is 125,000. Since there are 16 apartments per building this means that approximately each household uses the Sauna one hour every fourth week. According to a Swedish survey on household economy (SCB. 2010), the average number of members per household for multi-family dwellings is 1.62. Finally, with consideration to the statistical data, a rough estimation of the time distribution is the usage one hour every 45th day for each member of the Swedish household.

Table 7-7 The estimated variations of the moisture production rate from Sauna bathing.

Moisture generation from Sauna bathing [kg/day]		
Christian J. E. 1994	*Lstiburek J et al. 1994*	*Kalamees T. et al. 2006*
1.03	0 - 1.28	1.00

Almost no multi-family dwellings are equipped with a Sauna unit inside the living in Sweden hence I_f will only influence single family dwellings. The Incidence factor is assumed to be 18.8% for Sauna bathing. This number is based on the result from 8,211 telephone based interviews (SCB. 2006a). The main question was whether the residents had access or not to a Sauna. Consequently the percentage of people with access given by the survey would, for example, also include access at a fitness center or at work. About 9% of the members in multi-family dwellings have access to a Sauna (SCB. 2006a); hence half of them would then have access elsewhere than at the residence. About 4% of the multi-family dwellings in Sweden have a Sauna unit (Tolstoy, N. *et al.* 1993). Regarding single family dwellings, 23.9% of the household members consider themselves to have access to Sauna bathing. Consequently the same distribution due to elsewhere access are applied on this figure an assumed Incidence factor will be equal to 18.8%.

7.4 Whirlpool

The time and duration distributions for whirlpools in dwellings are assumed to be equivalent with the time distribution for bathing in a bath tub as described in Chapter 7.1. As for the activity of bathing in a bath tub, the moisture generation from a whirlpool is estimated with Equation (7-1) (ASHRAE 2007).

The bubble mechanism of a whirlpool result in a more active water surface compared to a residential bath tub, hence the Typical Activity Factor, F_a, for whirlpools is equal to 1.0. For this reason the total evaporation rate from whirlpools is considered twice the evaporation rate from a bath tub at corresponding conditions.

The area of the water surface for residential whirlpools varies between 0.8 and 1.1 m^2 (Ifö/Products. 2010a). Other input data which are relevant for estimating the water evaporation from whirlpools are given in Table 7-4. The mean Incidence factor, I_f is equal to 2.3% for a whirlpool. This means that with no consideration to type of residence the probability to possess this type of installation is 2.3%. In consideration with the type of residence the Incidence factor is 0% for multi-family dwellings and 4.8% for single family dwellings.

7.5 Food preparation

Preparing breakfast, lunch and dinner usually result in a moisture generation and together they define the indoor moisture source from food preparation. The probability for these events to occur during the day is presented in the Swedish time user survey (SCB. 2003), see Figure 7–2.

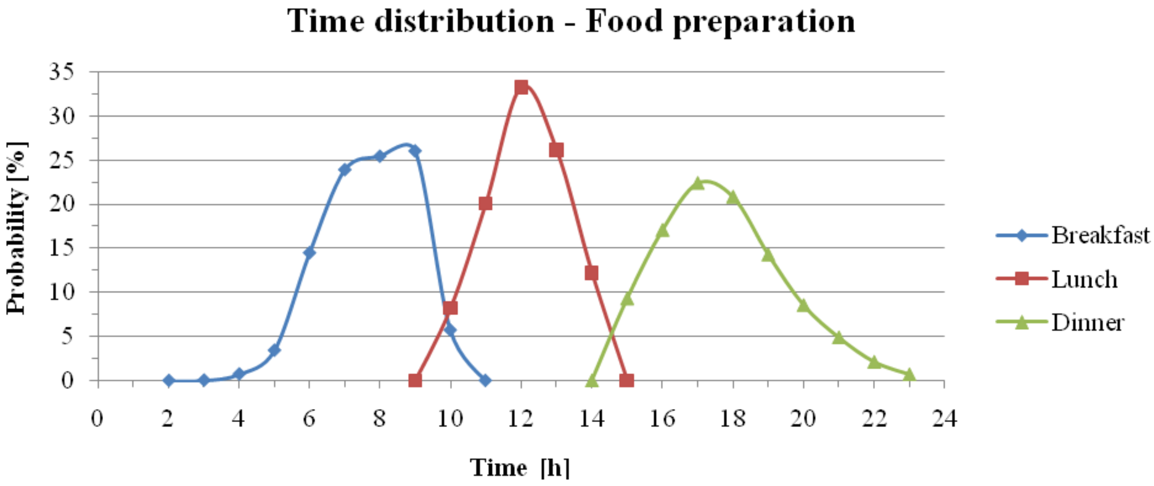

Figure 7–2 The time distribution for food preparation consist of the three major activites breakfast, lunch and dinner. Their probabilstic are defined in the Swedish time user survey (SCB. 2003).

The Incidence factor with consideration to food preparation is essential if a realistic time distribution should be established. People tend to eat outside the household more frequently during weekdays in comparison to weekends (Carlsson-Kanyama, A. *et al*. 2003). For this reason the time distribution must be adjusted to the probability of consuming a meal which is not prepared inside the living.

Table 7-8 The time distribution for food preparation must be adjusted to the behavior of preparing and consuming a meal outside the household. The probibalistics are given by a survey on energy consumptions in Swedish household (Carlsson-Kanyama, A. et al. 2003).

Consuming a meal outside the household on weekdays.	**Probability**	**Consuming a meal outside the household during weekends.**	**Probability**
More than once per day	2.5%	More than once per day	2.8%
Once per day	34.0%	Once per day	8.7%
4 to 5 times per 5 weekdays	16.4%	Less than once per weekend	86.5%
1 to 3 times per 5 weekdays	24.5%	No response	2.0%
Less than once per 5 weekdays	22.0%		
No response	0.7%		

Food preparation is generally described as a specific amount of moisture production with no information on the duration of the activity. There is available information of the contribution from each sub activity such as boiling, frying or coffee brewing (ASHRAE. 2005) but this information is rather complicated to use if no coupled user behavior is established. The amount of moisture released varies greatly according to the cooking methods (Angell, W.J. & Olson, W.W. 1988). For example, the Chinese food cooking process generates a large amount of moisture due to stir frying and boiling (Yik, F.W.H. *et al.* 2004).

A few of the studies made manage to quantify the amount of moisture generated from each meal i.e. from breakfast, lunch or dinner (Angell, W.J. 1988; Yik, F.W.H. *et al.* 2004). Usually if any information is given regarding the amount of moisture generated from the food preparation process it is presented on 24-hour basis (CIBSE. 1999; Rousseau, M.Z. 1984; Hansen, A.T. 1984). As a suggestion, an estimation of the impact from each three activities could be obtained using the percentage patterns from the studies were such clarification has been made.

Table 7-9 The moisture generatation from breakfast, lunch and dinner can be estimated using the percentage pattern from the studies were such distribution is presented. (Angell, W.J. & Olsson, W.W. 1988; Yik, F.W.H. et al. 2004).

Food Preparation	*Angell 1988* [kg]	 [%]	*Yik F.W.H 2004* [kg]	 [%]	**Mean**
Breakfast	0.17	17%	0.52	13%	**15%**
Lunch	0.25	25%	1.75	44%	**34%**
Dinner	0.58	58%	1.75	44%	**51%**

The process of clarifying the contribution from breakfast, lunch and dinner is important when establishing a simulation model of indoor moisture supply. The contribution from each activity can be estimated using the pattern given by Table 7-9, derived from studies where clarifications have been made on the influence from each meal preparation. Once each activity is estimated the spreading of the values and a variation of the distribution can be obtained.

Table 7-10 The pattern obtained in Table 7-9 gives a rough estimation of the contributions from each activity when applied on the values of total moisture amount from food preparation. Together the spreading of the values enables a prediction of a mean value and a standard deviation. L=Lower estimated moisture amount and U=Upper estimated moisture amount, /1/ (Angell, W.J. & Olsson, W.W. 1988), /2/ (Yik, F.W.H. et al. 2004), /3/ (CIBSE. 1999), /4/ (Rousseau, M.Z. 1984), /5/ (Hansen, A.T. 1984.), /6/ (Christian, J.E. 1993).

Total	**1.00**	**4.02**	**5.06**	**0.90**	**3.00**	**1.00**	**0.92**	**2.40**	**[kg]**
Breakfast	*/1/* L	*/1/* U	*/2/*	*/3/* L	*/3/* U	*/4/*	*/5/*	*/6/*	
m	0.17	0.52	0.26	0.13	0.45	0.15	0.14	0.36	[kg]
σ:	**0.05**								[kg]
μ:	**0.273**								"
Lunch	*/1/* L	*/1/* U	*/2/*	*/3/* L	*/3/* U	*/4/*	*/5/*	*/6/*	
m	0.25	1.75	0.95	0.31	1.03	0.34	0.32	0.82	[kg]
σ:	**0.17**								[kg]
μ:	**0.721**								"
Dinner	*/1/* L	*/1/* U	*/2/*	*/3/* L	*/3/* U	*/4/*	*/5/*	*/6/*	
m	0.58	1.75	3.86	0.46	1.52	0.51	0.47	1.22	[kg]

σ:	**0.38**								[kg]
μ:	**1.295**								"

Where: m = Moisture production of a specific meal. [kg]

σ = Standard deviation [kg]

μ = Mean value of a specific meal. [kg]

The amount of moisture from the source of food preparation is generally described as an average based on a family of four (Christian, J.E. 1994). This assumption complicates the simulation of indoor moisture supply when the household consists of other than a four-member family. The amount of moisture produced when preparing a meal for two persons is probably not half of the production when preparing a meal for four persons. As an example, when boiling rice the portion of water in comparison with the portion of rise decreases with the increased amount of servings according to the recipes on the rice packages.

In order to make realistic simulations of the moisture production from the food preparation process an estimation of a weighted distribution must be made. In this study an assumption will be to decrease or increase the given values with 25% for each member less or more than a four-member family. Subsequently a single person household produces about 40% of the predicted four member's value.

7.6 Hand dishwashing

The activity of dishing is influenced on whether the household are equipped with a Dishwashing machine or not. The probability of doing the dishes decreases if the household uses a dishwashing machine (HETUS. 2005-2007) and the probabilistic is presented in Figure 7–3. The Incidence factor regarding a Dishwashing machine will be investigated in Chapter 7.7.

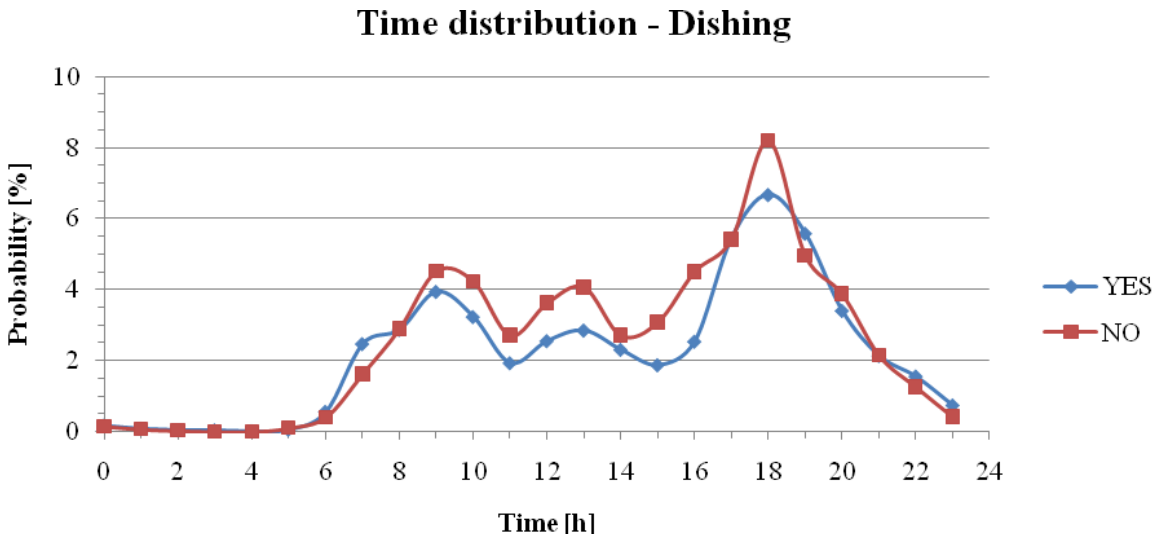

Figure 7–3 The time distributions for dishing reveal a difference whether the household is equipped with a Dishwashing machine or not (HETUS. 2005-2007).

The average time spent on dishing during a year generally varies between 25 and 32 minutes per day (HETUS. 2005-2007) and by interpreting the graphs they seem to peek in accordance with the activity of breakfast, lunch and dinner. The time probability of dishing is more important than the duration of the activity due to the reason that the moisture production is generally described as an estimated moisture production rather than a moisture production rate.

Moisture added to the surrounding air during hand dishwashing is greatest during the hot water rinsing of the dishes (Angell, W.J. & Olson, W.W. 1988). In a Swedish survey made on energy consumption a question on whether the household rinsed the dishes while the water was running or not, was part of the questionnaire. The result revealed that 53.8% of the household in single family dwellings let the water running while doing hand dishwashing and corresponding 68.8% in multi-family dwellings (Carlsson-Kanyama, A. *et al.* 2003). How much influence this behavior has on the total amount of moisture production from hand dishwashing is still to be investigated.

The moisture levels due to the activity of doing the dishes are presented by **Fel! Hittar inte referenskälla.**. All values are based on a family of four members, hence a weighting of the levels is necessary if arbitrary values for the simulation model in this study are to be estimated.

Table 7-11 The moisture production from hand dishwashing with or without the correlation of the meals consumed. The values in paranthesis indicates that this source has presented an average daily value which is weighted in accordance with the percentage pattern from the study were such distribution is presented (Angell, W.J & Olson, W.W. 1988).

Moisture production - Dishing	*Angell/Olson 1988*	*Hansen 1984*	*Rousseau 1984*	*Chrisitian J.E. 1993*	*CIBSE 1999*	
Breakfast	0.10	- / (0.09)	- / (0.12)	- / (0.10)	- / (0.09)	[kg]
Lunch	0.08	- / (0.07)	- / (0.10)	- / (0.08)	- / (0.07)	"
Dinner	0.32	- / (0.29)	- / (0.38)	- / (0.32)	- / (0.29)	"
Daily average	0.50	0.45	0.60	0.50	0.45	"

According to a Chinese study the assumed moisture production is in direct relation with the number of persons in the household (Yik, F.W.H. 2004). This assumption is not made in this study since it is not likely that the number of accessories used during the food preparation process increases linearly with the number of servings. For the same reason as described in Chapter 7.5 the purpose of creating a weighted distribution of the levels of moisture production is to make realistic data for the simulation model. As for food preparation, an assumption will be to decrease or increase the values of the given moisture production with 25% for each member less or more than a four-member family.

7.7 Dishwashing machine

The probabilities for using the Dishwashing machine are given by an American survey made on 4,381 households (EIA. 2008). The usage varies between more than once per day to less than once per week and is presented by Table 7-12.

Table 7-12 The time probability for using the Dishwashing machine based on either type of accommodation or number of persons in the household (EIA. 2008).

Time probability - Dishwashing machine	**Single family**	**Multi-family**	**Number of persons in the household**				
			1	2	3	4	≥ 5
Once or more per day	19.0%	8.2%	2.3%	12.4%	20.0%	26.4%	46.3%
4 to 6 times per week	19.7%	10.2%	4.6%	16.7%	26.4%	27.4%	20.9%
2 to 3 times per week	34.3%	31.6%	35.1%	43.8%	30.0%	25.5%	14.9%
Once per week	12.8%	19.4%	27.5%	14.2%	9.1%	6.6%	4.5%
Less than once per week	14.0%	30.6%	29.8%	12.9%	14.5%	13.2%	14.9%

In order to create a realistic time distribution of the probabilistic given by Table 7-12 the time distribution curve from the activity of dishing in the Swedish households are used (HETUS. 2005-2007). Based on whether the probability will rely on type of accommodation or the number of persons in the household, five different curves will follow for each category. The time distributions from the five behavioral patterns are presented in Figure 7–4.

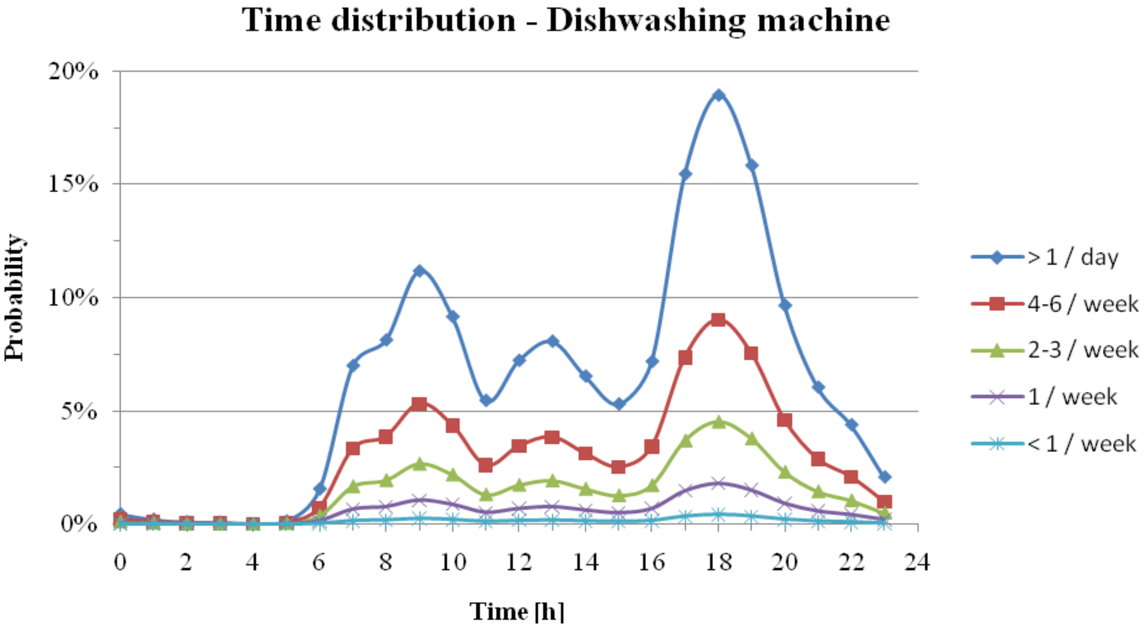

Figure 7–4 The time distribution for using the Dishwashing machine in a single family dwellings. There are five different curves for the probability based on the survey questionaire. The shape of the curves are in accordance with the activity of dishing in Swedish households (HETUS. 2005-2007).

The Dishwashing machine produces moisture during the drying cycle of the working program. Depending on the efficiency of the drying process a certain amount of moisture will be generated after the working program is finished and the hatch of the Dishwashing machine has been opened. The total moisture production when running a Dishwashing machine varies between 0.2 and 0.4 kg. The variation of moisture production depends on the amount of load in the machine, the excess of water within and the effectiveness of the rinse in the dishwashing detergent (Härefors, G. 2010). If the drying process is well-functioning most of the excess water is taken care of during this part of the working program. If the drying process is ineffective a larger amount of moisture is released afterwards.

The working program of a Dishwashing machine normally runs for 2 to 3 hours (Härefors, G. 2010). The moisture production rate for a Dishwashing machine is 0.180 kg/h (ASHRAE. 2005) which seems consistent with previously described variation of 0.2 and 0.4 kg.

Table 7-13 The Incidence factor for a Dishwashing machine varies greatly in a Swedish household depending on the number of members of the household and the type of accommodation (SCB. 2006a).

Incidence factor I_R- Dishwashing machine									
Number of persons in the household and type of accommodation [%]									
1		2		3		4		> 5	
Single family	Multi-family	Single family	Multi-family	Single family	Multi-family	Single family	Multi-family	Single family	Multi-family
43.9	13.4	70.3	34.2	80.7	45.9	87.5	40.1	86.2	52.5

The Incidence factor for a Dishwashing machine reveals whether the household is equipped with this appliance or not. In the Swedish household such information is given by a survey made on the living environment (SCB. 2006a) and is presented in Table 7-13.

Noteworthy is that an additional contribution to the total moisture generation may depend on whether the household rinses the dishes before it is loaded into the machine or not. As described in Chapter 7.6 the moisture added to the surrounding air during hand dishwashing is greatest during the hot water rinsing of the dishes (Angell, W.J. & Olson, W.W. 1988). Since 37% of the Swedish household rinses the dishes in hot water before loading it into the machine, though this is not considered in this study, this action ought to have some significance (Carlsson-Kanyama, A. 2003).

7.8 Laundry

If the drainage of the waste water works properly, the process of washing clothes in a washing machine does not generate moisture (Angell, W.J. & Olson, W.W. 1988). Instead a possible moisture production into the indoor environment may appear during the drying process of the clothes which depends on the type of drying method. Even though the washing procedure normally does not generate moisture, it is still of great importance to determine the incidence of the appliance. By taking the time distribution of the user behavior for using the washing machine together with the amount of clothing washed into consideration, the demand for drying the clothes will be estimated.

When considering multi-family dwellings in Sweden it is common to do the laundries in mutual spaces. Only 33 percent of the households in multi-family dwellings have a washing machine inside the living. In single family dwellings this figure is believed to be almost 100 percent (Carlsson-Kanyama, A. *et al.* 2003). A more recent survey of the probability of having a washing machine inside the living shows similar variation (HETUS. 2005-2007). The distribution of the incidence factor is presented in Table 7-14 and varies with consideration to the number of members of the household and type of accommodation.

Table 7-14 The variation of the Incidence factor for a Washing machine in Sweden with regard to the number of members of the household and the type of accommodation (HETUS. 2005-2007).

Incidence factor I_R- Washing machine									
Number of persons in the household and type of accommodation [%]									
1		2		3		4		> 5	
Single family	Multi-family	Single family	Multi-family	Single family	Multi-family	Single family	Multi-family	Single family	Multi-family
86.8	23.9	97.9	41	97.4	47.8	98.9	56	97.9	55.4

There are mainly three ways of drying the clothes on residential basis. Either a drying cabinet or tumble drier is used, or the clothes are dried by unvented drying. The unvented drying takes place either indoors or outdoors. The incidence of electrical drying appliances is almost negligible in multi-family dwellings. In single family dwellings the incidence of a drying cabinet or a tumbler drier is 23% respectively 50% (Carlsson-Kanyama, A. 2003). An older study from 1993 reveals that the incidence of an electrical drying appliance in multi-family dwellings is about 3-4% (Tolstoy, N. *et al.* 1993). By interpreting the values it seems that of those residents living in multi family dwelling and are doing their laundries inside the living, about 90 percent must perform unvented drying. An American survey made by the American Energy Information Administration presents a much more plausible value for the incidence of having an electrical drying appliance in Sweden. The Incidence factor presented is 35.1% for multi-family dwellings hence about 65% of the households must perform unvented drying (EIA. 2008).

In order to estimate the demand for drying clothes the user behavior of the washing machine must be determined as well as the number of loadings. The user behavior of the washing machine is presented in Table 7-15 and presents the frequencies of doing the laundry with consideration to the number of members in the household (EIA. 2008).

Table 7-15 The time probability for doing the laundry with varations due to the number of household members (EIA. 2008).

Usage of Washing machine per household	**Number of persons in the household**				
	1	**2**	**3**	**4**	**≥ 5**
> 15 loads / week	0.0%	0.0%	2.5%	4.3%	10.4%
10 - 15 loads / week	0.0%	5.0%	13.8%	18.6%	24.5%
6 - 9 loads / week	14.1%	37.9%	48.4%	53.6%	39.6%
2 - 5 loads / week	61.0%	51.8%	32.1%	20.7%	23.6%
1 load / week	23.9%	4.3%	2.5%	2.1%	0.0%

The subsequent action of running the washing machine is the drying process. The Incidence factors due to type of drying method are described in Table 7-16. The values in the table comprise the total amount of Swedish households which then means that the Incidence factor of an electrical drying appliance must be adjusted to the Incidence factor of a washing machine given in Table 7-14. For this study two assumptions will follow. First, the amount of households using unvented drying will be estimated by using the remaining number of households with a washing machine and with no electrical drying appliance. Second, the probability of having both a drying cabinet and a tumbler drier is not considered to be a commonly occurring since either scenario is assumed.

Table 7-16 The Incidence factors due to type of drying method in Swedish households. The values are based on the total amount of households with the appliance, hence a comparison must be made to the incidence of having a washing machine (Carlsson-Kanyama, A. et al. 2003; Tolstoy, N. et al. 1993; EIA. 2008).

Incidence factor - Drying method in Swedish households [%]			
Drying method	Single family	Multi-family	Combined
Drying cabinet	23.0	3.0	12.0
Tumbler drier	50.4	35.1	42.4

The moisture generation from doing the laundry is negligible when considering the washing process (Yik, F.W.H. *et al.* 2004). The drying process on the other hand is a decisive residential moisture source depending on type of drying method. As described earlier the amount of loadings are important as well as the amount of clothes per loading. In Sweden the washing machine is usually fully loaded before the washing program is initiated. The probability of running a fully loaded washing machine is 85 percent for single family dwellings and 78 percent for multifamily dwellings (Carlsson-Kanyama, A. *et al.* 2003).

The user behaviors for drying appliances are given in Table 7-17 and reveals how often it is used depending on type of accommodation. The values listed by the table comprise only those household equipped with the considered electrical drying appliance.

Table 7-17 The probability of using an electrical drying appliance subsequent to the washing process (EIA. 2008).

Usage behavior - Clothes drying Time probability	**Type of accommodation**		
	Single family	Multi-family	Combined
All the times	82.2%	86.0%	82.7%
Frequently	14.8%	9.3%	14.2%
Infrequently	3.0%	4.7%	3.1%

Finally when the Incidence factors for all drying appliances are established as well as the user behaviors, the moisture levels from the activities must be estimated. The moisture generation mainly depends on the accumulated amount of water and vapor within the fabric of the clothes. The estimated levels of moisture production vary between 1.25 and 3.5 kg per load of wet clothes and are presented in Table 7-18. How much of the excess of water that effects the indoor environment depends on type of drying method. In a drying cabinet the excess moisture is considered to be completely taken care of by the exhaust ventilation system. A tumble drier usually reduces the moisture production from drying clothes with about 80 to 100 percent (Svantesson, K. 2010). The difference depends on whether the tumble drier works with exhaust air or condensation of water, the latter responds to 80 percent.

Unvented drying is a direct moisture source i.e. all moisture released during the drying process will be excess moisture to the indoor environment. The rate of moisture release is usually much slower for unvented drying compared to electrical drying appliances. The moisture generation rate depends on the type of clothing, the indoor relative humidity and the temperature of the indoor air. The drying process when performing unvented drying may last between 7 to 15 hours while about 20% of the total moisture generation occurs during the first hour (Yik, F.W.H. 2004).

Table 7-18 The estimated moisture generation from the drying process of wet clothing. The values are defined as the total amount of moisture released during unvented drying per loading of clothes.

Moisture Generation - Drying of wet clothes [kg/load]				
Angell W. J. 1988	*CIBSE 1999*	*Yik F. W. H. 2004*	*Rousseau M. Z. 1984*	*Hansen A. T. 1984*
2.2 - 2.92	1.25 - 3.5	1.66	1.75	1.92

7.9 Ironing

Ironing generates moisture when water is used together with the feature in order to facilitate the removal of creases. In Sweden 97 percent of the households have one or more irons (Carlsson-Kanyama, A. *et al.* 2003). The user behaviors for ironing are presented by Figure 7–5 and reveals very small differences between different household compositions (HETUS. 2005-2007). Considering all types of households, more than fifty percent use the iron less than once every week (Carlsson-Kanyama, A *et al.* 2003).

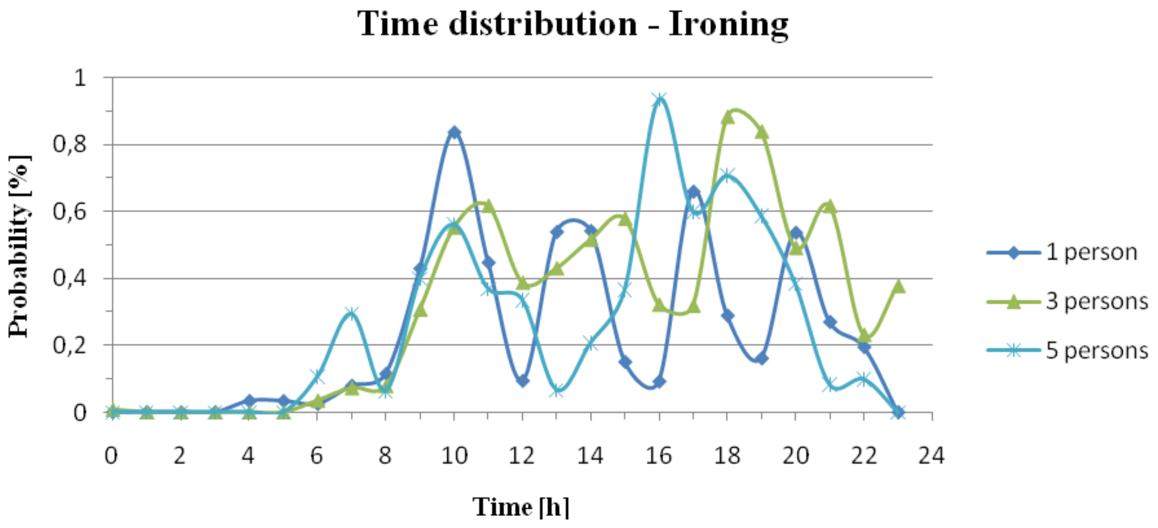

Figure 7–5 The time distribution for the activity of ironing shows small disparities between different household compositions (HETUS. 2005-2007).

The mean value for the duration of ironing in the Swedish households is 38 minutes and the monthly mean value varies between 31 and 53 minutes during the year (SCB. 2003).

The level of moisture generation rates depends on the user behavior and type of Iron. Water can be sprayed manually or steamed automatically onto the fabric. An average moisture generation rate for a steam Iron is 0.585kg per hour of usage according to a Chinese measurement study (Yik, F.W.H. 2004). Though an experiment of the moisture production from the activity of ironing seems rather simple to realize, such information was very hard to find. In this study the value from the Chinese measurements will be used when predicting the moisture production from ironing in Swedish households.

7.10 Floor mopping

There is no information found regarding the time distribution for the specific event of floor mopping in Sweden. Floor mopping is categorized under the category cleaning dwelling, which of course consists of several other activities. Despite the problematic with sub-division of logged activities as explained in 7.2, the time probability for floor mopping is assumed to follow the pattern from cleaning dwellings in Swedish household (HETUS. 2005-2007). The probabilistic is presented with difference due to weekdays or weekend in Figure 7–6.

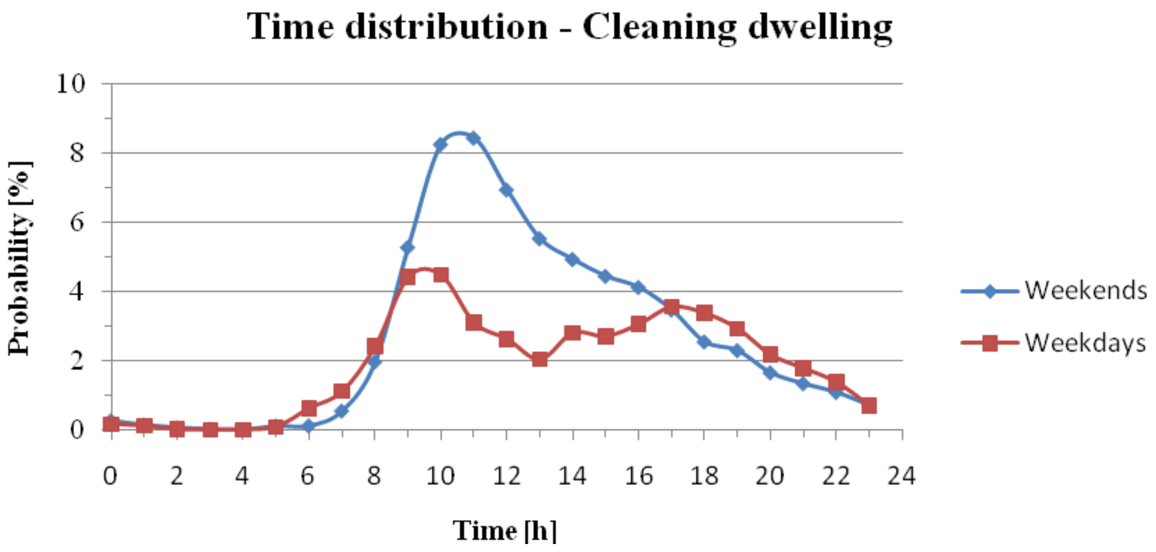

Figure 7–6 The time distribution for cleaning the dwelling will be used with the intention of estimating the time distribution for floor mopping in swedish households. There are clear differences in probability between working days and weekends.

In order to use the pattern from the activity of cleaning the dwelling, an assumption must be made regarding the correlation with floor mopping. In this study the activity of floor mopping is on average estimated to take place every second week with maximum of two times per week and a minimum of once every third month.

To be able to estimate the moisture generation from the activity of floor mopping, the residential floor area must be determined. Normally this information can be obtained from the data of a specific construction object i.e. the building which is to be analyzed. If no such data is given the residential floor area of the households can be estimated with the help of statistics from surveys made on household economics in Sweden (SCB. 2010). Table 7-19 describes how the floor area may vary due to type of accommodation and number of members in the household.

Table 7-19 The average residential floor area per member of the household varies with the type of accommodation and the total number of members in the household (SCB. 2010).

Average residential floor area per member of Swedish households [m^2]					
Accommodation type	**Number of members of the household**				
	1	**2**	**3**	**4**	**5 or more**
Single family	75-125	49-69	37-47	27-36	31
Multi-family	46-67	32-45	28	23-24	19-21

The estimated moisture generation when performing floor mopping varies between 0.1 and 0.15 kg per square meter according to several recommendations (CIBSE. 2009; Hansen, A.T. 1984; Rousseau, M.Z. 1984; Angell, W.J. & Olsson, W.W. 1988). A more recent Chinese study claims that these values of moisture generation are very high (Yik, F.W.H.). The Chinese study instead produces a value of 0.005 kg per square meter which seems very low, at least with reference to the applicability in Swedish households. A value of 5 g per square meter means that only a tablespoon of water evaporates from the floor surface when mopping the floor.

Today a floor mop may be more efficient to distribute less water onto the floor surface, hence the older recommendations of 0.15 seems rather high. In this study a linear variation between 0.01 and 0.1 kg per square meter will be used.

7.11 Humans

Humans contribute to the indoor moisture supply due to perspiration and respiration. The level of moisture generation mainly depends on the type of activity performed by the human and the surrounding air temperature (Christian, J.E. 1994).

Obviously the moisture generation from humans depends on the performed indoor activity since the activity pattern of the individuals inside the living must be estimated. Regarding Swedish households, such information is given by the online database for time user surveys (HETUS. 2005-2007). The type and structure of the household as well as the age of the individual are two greatly influential parameters when estimating the activity and user behavior of a household member. Table 7-20 and Table 7-21 display the mean duration for the category of individual specified and the probability for the event to take place inside the living. For example, the activity of sleeping is considered to take place every day but not necessarily inside the living, hence a probability below 100 percent is usually expected.

Table 7-20 and Table 7-21 define five categories of possible individuals among the Swedish household; single parents with a child or children, single persons, children or persons living together with a parent and married or cohabited persons with or without children. The activity pattern for these categories of household members differs depending on type of day i.e. there is a difference how time is spent depending on whether the day in consideration is a working or school day or a day during a weekend or holiday.

When simulating human activity patterns, Table 7-20 and Table 7-21 must be complemented with time distribution curves like Figure 7–1. The tables only show the likelihood of an event to take place inside the living and do not specify at what time during the day. The time distribution curves needed for simulation will not be presented in this paper but will be constructed in the simulation program for indoor moisture production.

Table 7-20 The activity pattern for single parents and cohabited parents during working days and weekends. For each activity the duration is given together with the probability for the activity to occur during the day and inside the living (HETUS. 2005-2007). Estimated moisture production rates for each activity are presented to the right-hand side of the table (ASHRAE. 2005).

User behavior - Time spent at home due to type of physical activity.		**Single parent with child/children**				**Married/Cohabited person with child/children**				**Prod. rate**
		Weekdays		Weekends		Weekdays		Weekends		
Activity		[min]	[%]	[min]	[%]	[min]	[%]	[min]	[%]	[g/h]
[1]	Sleep	404	96.0	508	95.1	420	98.6	510	97.3	30
[2]	Eating	54	92.6	68	94.1	58	96.6	90	95.6	66
[3]	Other personal care	44	88.6	46	89.1	41	95.1	41	92.7	81-100
[4]	Main and second job	162	15.4	0	0.0	144	15.3	79	10.1	66-100
[5]	Homework	0	0.0	0	0.0	0	0.0	0	0.0	66
[6]	Food preparation	33	78.8	49	87.8	36	75.0	59	76.3	81
[7]	Dish washing	22	50.0	27	74.1	22	59.1	32	62.5	81
[8]	Cleaning dwelling	32	46.9	57	75.4	27	44.4	53	58.5	81-118

[9]	Other household upkeep	0	0.0	0	0.0	36	5.6	57	10.5	100-206
[10]	Laundry	32	28.1	43	44.2	26	23.1	36	33.3	100-206
[11]	Ironing	0	0.0	35	11.4	36	8.3	53	9.4	81-118
[12]	Handicraft	0	0.0	0	0.0	0	0.0	53	3.8	66-118
[13]	Caring for pets	0	0.0	18	11.1	19	5.3	22	13.6	66
[14]	Construction and repairs	0	0.0	0	0.0	71	8.5	77	19.5	100-272
[15]	Supervision of child	33	51.5	48	52.1	26	38.5	31	35.5	66-100
[16]	Teaching/reading w. child	32	37.5	42	40.5	34	32.4	39	28.2	51-100
[17]	Other domestic work	22	31.8	26	42.3	29	34.5	40	37.5	81-118
[18]	Visits and feasts	0	0.0	89	10.1	0	0.0	94	11.7	51-66
[19]	Other social life	35	42.9	41	51.2	29	51.7	45	53.3	51-66
[20]	Resting	33	30.3	35	37.1	36	22.2	45	35.6	44-51
[21]	Computer	0	0.0	73	17.8	45	11.1	51	19.6	44-51
[22]	Other hobbies and games	0	0.0	56	8.9	44	6.8	65	12.3	44-66
[23]	Reading books	46	10.9	51	17.6	37	16.2	63	17.5	44
[24]	Other reading	31	35.5	45	40.0	31	41.9	42	42.9	44
[25]	TV and video	87	70.1	139	75.5	90	78.9	140	77.9	44-51
[26]	Radio and music	0	0.0	0	0.0	0	0.0	34	8.8	44-51

Table 7-21 The activity pattern for cohabited and single persons of a household with no children together with the activty pattern for children living in parents household. For each activity the duration is given and the probability for the activity to occur during the day and inside the living (HETUS. 2005-2007).

	Married/Cohabited person with no child/children				**Single person with no child/children**				**Person living in parents household**			
	Weekdays		Weekends		Weekdays		Weekends		Weekdays		Weekends	
	[min]	[%]	[min]	[%]	[min]	[%]	[min]	[%]	[min]	[%]	[min]	[%]
[1]	411	97.6	508	93.3	429	97.7	506	93.5	474	100.0	590	100.0
[2]	62	96.8	103	92.2	47	95.7	75	90.7	95	100.0	92	97.8
[3]	44	93.2	48	87.5	44	93.2	47	87.2	52	96.2	55	96.4
[4]	136	14.0	71	8.5	0	0.0	0	0.0	0	0.0	0	0.0
[5]	0	0.0	0	0.0	0	0.0	0	0.0	146	63.7	161	19.3
[6]	34	70.6	70	77.1	33	75.8	53	83.0	29	72.4	39	61.5
[7]	20	45.0	32	59.4	20	40.0	27	63.0	0	0.0	24	41.7
[8]	34	44.1	55	56.4	38	44.7	55	60.0	27	44.4	52	48.1
[9]	36	5.6	58	8.6	0	0.0	0	0.0	0	0.0	0	0.0
[10]	26	15.4	40	25.0	29	20.7	35	22.9	0	0.0	40	12.5
[11]	31	9.7	42	14.3	0	0.0	0	0.0	0	0.0	0	0.0
[12]	0	0.0	56	5.4	0	0.0	0	0.0	0	0.0	0	0.0
[13]	22	9.1	24	8.3	0	0.0	0	0.0	0	0.0	0	0.0
[14]	70	8.6	87	18.4	0	0.0	0	0.0	0	0.0	0	0.0
[15]	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
[16]	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
[17]	29	34.5	38	34.2	21	33.3	52	26.9	0	0.0	39	17.9

[18]	62	6.5	102	17.6	0	0.0	0	0.0	0	0.0	163	36.2
[19]	35	45.7	40	50.0	36	47.2	45	55.6	76	61.8	114	64.0
[20]	41	29.3	59	37.3	41	36.6	58	34.5	0	0.0	54	38.9
[21]	59	10.2	57	12.3	0	0.0	0	0.0	0	0.0	92	28.3
[22]	35	8.6	66	19.7	0	0.0	64	21.9	0	0.0	118	18.6
[23]	40	17.5	67	19.4	51	21.6	79	21.5	0	0.0	0	0.0
[24]	39	48.7	52	53.8	43	46.5	57	49.1	0	0.0	39	23.1
[25]	107	79.4	153	79.7	97	73.2	143	72.0	108	73.1	162	77.8
[26]	26	7.7	38	13.2	53	18.9	80	21.3	0	0.0	37	13.5

In order to estimate the total influence from the human body on the indoor moisture production the composition of the household must be estimated. The five categories of possible individuals inside the Swedish households vary with type of accommodation according to Table 7-22.

Table 7-22 The probability for each type of individual with consideration to the composition of Swedish households (SCB. 2010).

Probability due to type of household individual [%]	**Type of accommodation**		
	Single family	**Multi-family**	**All**
Single person with no children	8.99	34.46	43.45
Married/Cohabited person with no children	15.32	10.86	26.19
Single parent with children	1.80	3.53	5.32
Married/Cohabited person with one child	3.98	2.73	6.71
Married/Cohabited person with two children	7.55	2.04	9.59
Married/Cohabited person with three or more children	2.69	0.82	3.50

The moisture generation from humans varies with type of physical activity according to Table 7-23. The rates vary between 0.03 and 0.3 kg per hour for a human body (Christian, J.E. 1994). The moisture production from humans can reach values of almost 0.5 kg per hour if extremely hard physical work is expected (ASHRAE. 2005). The estimated rates of production are given to the right-hand side of Table 7-20 for each activity defined.

The activities result in moisture generation rates which are based on the mean values of fully grown men. In order to estimate the moisture production from women and children the values are to be reduced with 85 and 75 percent respectively (ASHRAE. 2005).

Table 7-23 Estimated rates of moisture generation from humans with consideration to type of physical activty. The values varies between the state of sleeping and hard work.

Moisture generation – Perspiration and Respiration [kg/h/person]			
Activity:	*Christian J.E. 1994*	*CIBSE 1999*	*Yik F.W.H. 2004*
Sleeping			0,043
Light activity	0,03-,12	0,04-	0,065
Medium activity	0,12-,20	-	0,079
Hard activity	0,2-0,3	-0,1	0,102

7.12 Pets

Pets produce moisture generally through both perspiration and respiration. As a suggestion the amount of moisture generated can be estimated using the ratio body weight of the pet in proportionate to the body weight of an adult human (Angell, W.J. & Olson, W.W. 1988).

The incidence for a household to have pets in Sweden is given by Table 7-24. The probability reveals whether a household has at least one of the specified animals or not. There are 1.73 cats in the Swedish household if the household owns at least one cat. Corresponding incidence is 1.32 for dogs (SCB. 2006b).

Table 7-24 The probabilities of having pets in Swedish households (SCB. 2006b). The body mass variation within the species mainly depend on type of breed, sex and age of the animal. The moisture production rate from household pets are based on a default physical activity rate from an adult human together with assumed variations of pet body masses.

Incidence factor - Household with pets in Sweden			
Species	**Probability [%]**	**Body mass [kg]**	**Moisture prod. [g/h]**
Dogs	12.8	3.0-65.0	2.48-53.6
Cats	16.8	4.0-11.0	3.30-9.08
Rabbit	2.0	0.4-3.0	0.33-2.48
Guinea pig	1.0	0.7-1.2	0.58-0.99
Birds	1.9	0.05-1.0	0.04-0.83
Mouse/Rat	0.34	0.03-0.65	0.02-0.54
Turtle	0.25	0.3-5.0	0.25-4.13
Reptile	0.35	0.01-20.0	0.01-16.5

The estimation of the contribution from pets varies with the given mean values of body mass for pets according to Table 7-24. In this study the rate of moisture generation from pets is assumed to be constant throughout the day. There will be no adjustment of the moisture generation due to type of physical activity. In this study a moisture generation of 66 gram per hour will serve as default value when estimating the corresponding rate from household animals. The default value is equivalent to the physical activity of a male person at seated position and performing light work (ASHRAE. 2005). The moisture generation from pets will be estimated with the help of weighting the default value multiplied with the body mass ratio i.e. the ratio between the body mass of the specific species and an adult human. The estimated variations of moisture generations are presented to the right-hand side of Table 7-24.

7.13 Aquarium

The moisture generation from an aquarium depends on the evaporation rate of the water. In Chapter 7.1, several parameters are discussed which influence the evaporation rate from a wet surface. The major factors controlling the rate of evaporation are air and water temperature, surface area of the water, air circulation speed and relative humidity (Natarajan, M. *et al.* 2009).

Very little specific information on the evaporation rate from aquariums is found. At several forums for aquarium users, estimations are made on the amount of water needed to be added due to water evaporation. The values vary between 3 and 10 kg per week mainly depending on whether the aquarium is hooded or not. The evaporation of water is also influenced on how the water pump system affects the air circulation at the water surface. Discussion of the influence on evaporation depending on the size of the aquarium is also common i.e. the surface area exposed to the indoor environment.

A measurement made in India presented a value of about 2.2 kg per square meter evaporated daily (Natarajan, M. *et al.* 2009). The surface area of residential aquariums is considered to vary between 0.25 and 1.0 square meters (Fridhems akvarier. 2010). If implementing the Indian measured value on the surface area variations, an estimated evaporation between 3.85 and 15.4 kg per week is obtained. Since the variations from the implementation seems rather consistent with the estimated values from aquarium forums, the previous variations between 3 and 10 kg per week will be used in this study. The corresponding variations of daily rates are 0.4 to 1.4 kg.

The incidence of aquariums in Sweden is 4.0 percent according to a survey made on pets in Swedish households (SCB. 2006b).

7.14 Plants

Indoor plants are considered as an indoor moisture source since the watered soil and the plant evaporates water (Yik, F.W.H. *et al.* 2004). In fact, almost the entire amount of water from watering the plant evaporates into the indoor environment. Only 0.2 percent of the water is used for growth (Christian, J.E. 1994).

The levels of moisture generation depend on the size, type of the plants and watering practices (Angell, W.J. & Olson, W.W. 1988) together with the indoor temperature, humidity and exposure to solar radiation. There are great variations of the suggested amount of moisture evaporation from plants according to Table 7-25. Some of the studies made present variations between 0.10 and 0.50 kg per plant and day, where the higher value represent the moisture generation from a medium size rubber plant (Christian, J.E. 1994). Other studies suggest mean values of 0.08 and 0.065 kg which is based on measurements made on various types of plants (Rousseau, M.Z. 1984; Angell, W.J. & Olson, W.W. 1988). A Chinese experiment revealed a moisture generation of one plant to be 0.02 kg per day (Yik, F.W.H. *et al*. 2004). This study was conducted with a rather small plant, at room temperature of 15°C and with an indoor relative humidity of 65 percent hence a lower value of moisture generation ought to be expected.

Table 7-25 The moisture production from indoor plants with suggested variations on daily basis.

Moisture generation - Indoor plants [kg/day/pc]				
Christian 1994	Trechsel 2001	Rousseau 1984	Yik *et al*. 2004	Angell 1988
0.12-0.5	0.1-0.36	~ 0.08	~ 0.02	~ 0.065

In this study the moisture production from indoor plants will be assumed to vary between 0.04 and 0.15 kg per day and plant during the summer and with a reduction of 50 percent during the winter. The assumed variations are meant to simulate the variation due to size and type of plant together with seasonal variations.

The incidence of indoor plants in Swedish households will be based on the assumption of one plant for every 7.5 square meter of residential floor area.

8 VENTILATION

The indoor moisture supply is a direct result of the moisture production inside the building envelope. The supply becomes the difference in water vapor content between the supply and exhaust air where the significance of the moisture production on the indoor moisture supply is mainly governed by the ventilation i.e. the air exchange rate, n [1/h]. In dwellings the exchange of air is due to natural or mechanical ventilation, leakages through cracks in the building envelope and airing through windows and doors (Dyrstad, P.T. 1997).

With the exclusion of the moisture buffer capacity of the surrounding materials the vapor content of the exhaust air, v_i changes over time according to the following Equation:

$$v_i = v_e + \frac{G}{n \cdot V} \cdot (1 - e^{-nt}) \tag{8-1}$$

where:

v_e = Moisture content of the supply air	[kg/m^3]
G = Moisture production rate	[kg/h]
n = Air exchange rate	[1/h]
V = Air volume	[m^3]
t = Time	[h]

Few of the studies and measurements made on the actual indoor moisture supply thoroughly explain the consequences on the result due to the location of the measuring equipment. Most of the measurements are performed in either the bedroom or the living room; hence the consequence of moisture production inside the kitchen or the bathroom is difficult to analyze (Jensen, L. 2010a). In a Swedish study made on 1,148 dwellings a passive tracer gas method was used to measure airflow rates. The equipment was placed in the living room due to the reason that this space has the highest fresh air supply (Stymne, H. *et al.* 1994).

Regarding field measurements, it is of great concern to consider what type of building or room they represent, in which country, duration of method and at what time of the year the measurements were performed (Geving, S. 1997). In order to perform risk assessment on a specific building technique at a specific position in the building envelope, realistic input data must be determined. If using measured data of the moisture supply in the living room, same data cannot be used when simulating the environment in the space of the kitchen.

The determination of the location of a moisture source inside the living is essential when establishing arbitrary indoor moisture conditions. To facilitate the interaction between moisture sources and spaces inside the living a network airflow model is established. These models idealize a building as a collection of zones, such as rooms and duct joints, joined by flow paths representing doors, windows, fans and ducts (ASHRAE. 2009). A possible network of the airflow inside a living is illustrated by Figure 8–1.

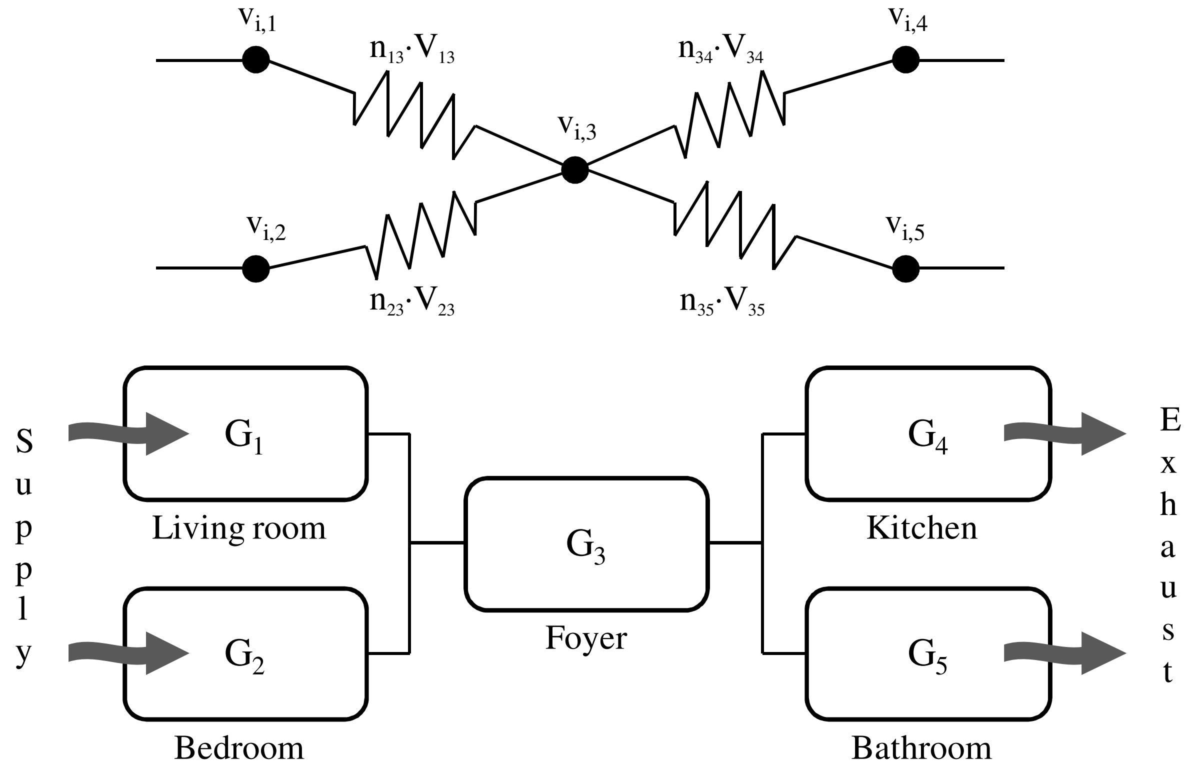

Figure 8–1 Network airflow model and space illustration of a plausible apartment design. The conductance of the network is described as airflow volume per second, [m3/h] and the moisture sources G, [kg/h] for each space described.

According to the network assembly in Figure 8–1, the moisture supply inside the foyer, $v_{i,3}$ will be influenced by both the moisture generation in the living room, G_1 and the bedroom, G_2 as well as the moisture generation inside the foyer, G_3. The disparity in the supplying airflow into the space of the foyer will govern the influence from the living room and the bedroom. The network airflow model described and the flow pattern is a suggested approach when estimating realistic moisture supply for a specific space in consideration. The procedure enables an arbitrary estimation of the moisture supply when performing risk assessment on certain technical solution for both new and retrofitting projects.

8.1 Ventilation system

The relative humidity of the indoor air is greatly influenced by the type of ventilation system where natural ventilation usually results in higher values due to lower air exchange (Norlén, A. & Andersson, K. 1993), since the moisture supply is inversely proportional to the airflow (Jensen, L. 2010a). A heat recovery system also affects the relative humidity inside the living if a hygroscopic rotor is used, but also a metallic rotor will recycle moisture due to condensation on the rotor blades (Jensen, L. 2010b) and air leakage from the exhaust to the supply side.

In Sweden two major studies have been realized on air exchange rates in Swedish dwellings with regard to type of ventilation system (Norlén, U. & Andersson, K. 1993; Boverket. 2009). The results from the studies are presented in Table 8-1 which strengthens the hypothesis of a lower exchange rate if the living has natural ventilation compared to mechanical.

Table 8-1 The mean values of the air exchange rate presented in two Swedish studies (Norlen, U. & Andersson, K. 1993; Boverket. 2009). Both studies reveals that natural ventilation results in a lower air exchange rate compared to mechanical ventilation. The pattern applies for both single family and multi-family dwellings.

Air exchange rate [l/s,m^2]	**Single family**		**Multi-family**	
	Norlén, U. 1993	*Boverket 2009*	*Norlén, U. 1993*	*Boverket 2009*
Natural ventilation	0.172	0.230	0.258	0.276
Extract air system	0.218	0.242	0.303	0.354
Supply and Extract air system	0.271	0.312	0.339	0.383

Only two of the mean values presented in Table 8-1 satisfy the guiding values given by the National Board of Health and Welfare in Sweden. According to the guidelines, an inflow of outdoor air of at least 0.35 l/m^2 is recommended (Swedish National Board of Health and Welfare. 2009). The risk of developing asthma and other allergic symptoms increases with an insufficient inflow of fresh outdoor air. If the dwelling is not ventilated properly, the risk increases of mites and mould damage in the building as well as unacceptably high levels of radon.

9 STUDYING OBJECT

The building chosen for the applicability study is located in Märsta, north of Stockholm in Sweden. The building is part of a larger area with around 50 similar buildings which have two main types of external walls. The load bearing walls are made of concrete and the wall panels are non-bearing timber walls. During 2009 the building was retrofitted with 70 mm mineral wool and the supplementary insulation was mounted on the interior side of the external walls. The original windows were kept, but the internal glass pane was replaced with a two glass pane system filled with argon gas. The building is monitored in a research project at Lund University and some preliminary results and more information on the building can be found in (Stein, J. 2010). The plan drawing for the chosen apartment in this study is defined in Figure 9–1.

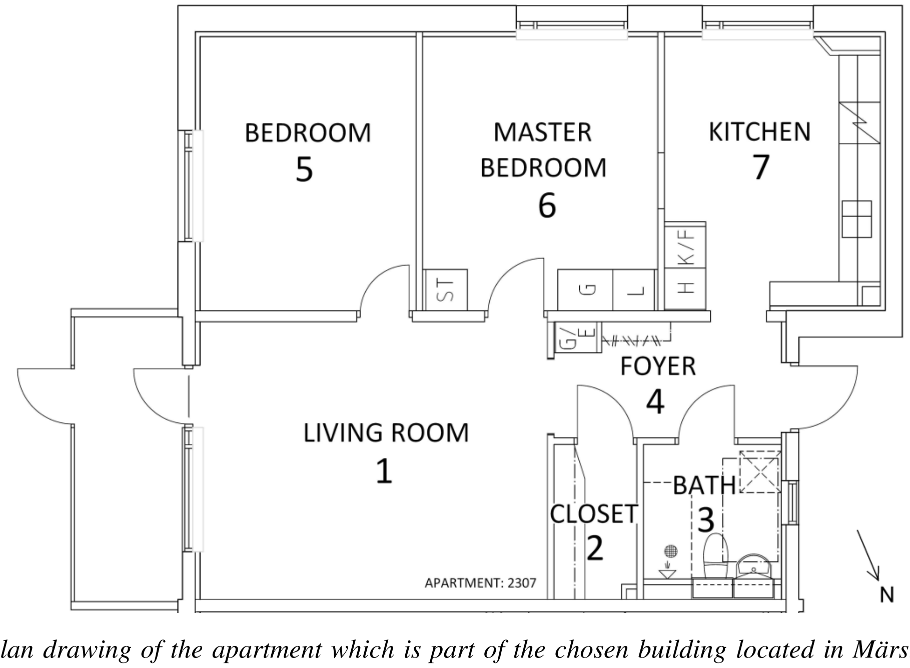

Figure 9–1 Plan drawing of the apartment which is part of the chosen building located in Märsta, Stockholm. The Total residential floor area is 70.9 m^2. Supply air devices are placed in the bedrooms and living room (1, 5, and 6) and extract air devices are located in the bathroom (3) and kitchen (7).

The total residential floor area of the apartment is 70.9 m^2 which is divided into rooms according to Figure 9–1. The ventilation air flows in the different rooms are provided by the building services engineer and represents the design values. No measurements of actual air flows have been performed.

Table 9-1 Residential floor area and ventilation rates in the rooms of the apartment. The roof height is 2.4 m in all rooms of the apartment.

#	Space	Ventilation rate	Room area
1	Living room	Supply 8 l/s	25.7 m^2
2	Closet	-	-
3	Bathroom	Extract 16 l/s	3.9 m^2
4	Foyer	-	-
5	Bedroom	Supply 7 l/s	12.4 m^2
6	Master bedroom	Supply 8 l/s	13.5 m^2
7	Kitchen	Extract 11 l/s and kitchen fan	11.9 m^2

There is an unbalanced air flow in the apartment which can be seen when summarizing the ventilation rates in Table 9-1. The supply air flow is in total 23 l/s and the extract air flow is 27 l/s. Not included in these numbers is the air flow through the kitchen fan which occasionally adds 50 l/s on the total extract air side.

If existing, the defined moisture sources must be placed in the spaces where they are likely to exist. The approach is essential in order to make real life simulations of the indoor moisture supply in each room of the apartment. Table 9-2 presents where each moisture source is assumed to be operating.

Table 9-2 The assumed location of the moisture sources in each room of the apartment. The moisture source associated with floor mopping comprises in all the defined spaces of the apartment.

#	Space	Moisture sources
1	Living room	Humans, pets, aquarium, plants, ironing.
2	Closet	-
3	Bathroom	Bathtub, tumbler drier, humans, showering, bathing.
4	Foyer	Humans, pets.
5	Bedroom	Humans, pets, ironing, plants.
6	Master bedroom	Humans, pets, ironing, plants.
7	Kitchen	Dishwashing machine, humans, food preparation, hand dishwashing, plants.

Obtaining climate data for the vicinity of the building have been proven difficult and therefore simulated weather data for Stockholm of the year 2000 will be used when making simulations on the indoor moisture supply. The average outdoor temperature for the studied year is 7.6°C with a maximum temperature of 21.3°C and minimum of -15.4°C. The average wind velocity is 3.0 m/s and the dominating wind direction is from southwest.

The air flow calculations between the zones of the studying object are performed in the computer software CONTAM. It is a multi-zone indoor air quality and ventilation software which is calculating the air flows between zones due to infiltration, exfiltration, mechanical ventilation, wind pressure and buoyancy effects. The program calculates the dispersion of contaminant concentrations, caused by these air flows (NIST, 2009). The building is divided into 5 zones (living room, master bedroom, second bedroom, kitchen and bathroom) in CONTAM as shown in Figure 9–2. The foyer is treated as a part of the living room and the closet is seen as a closed space. The studied contamination is the excess vapor content in the air which is produced inside the different rooms of the apartment where the distribution for each room is obtained from @Risk simulations of moisture production.

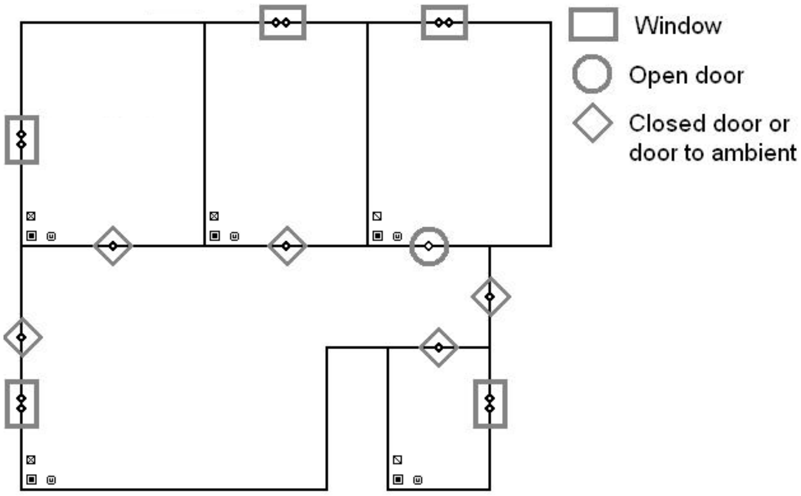

Figure 9–2 Leakage paths between the zones of the apartment and between the indoor and outdoor. Sizes and other properties of the leakage paths are desribed in Table 9-3.

The leakage paths between the different zones used in the CONTAM model are shown in Figure 9–2 and the data used in the calculation are presented in Table 9-3. Air infiltration through the building envelope is based on estimations of the air tightness after retrofitting. The air infiltration rate is 0.82 1/h (1.2 l/s, m^2) before retrofitting and it is estimated to be 0.45 1/h (0.65 l/s, m^2) after the retrofitting (Harderup, L-E. & Stein, J. 2010). The air flows presented in Table 9-1 for the mechanical supply and exhaust air flows are reduced by 3.5% due to the leakage of air from the exhaust air side to the supply air side through the regenerative heat exchanger (Jensen, L. 2008). This fact creates a larger moisture supply, since not all air supplied into the zone is fresh air, but a part is actually recirculated indoor air.

Table 9-3 Properties of leakage paths used in the CONTAM air flow model.

Part	Leakage size	Discharge coefficient	Flow exponent	Pressure difference	Elevation
Window	0.269 cm^2/m	1	0.65	4	0.8 and 2.1
Door to ambient	12 cm^2	1	0.65	4	1
Closed door between zones	12 cm^2	1	0.65	4	1
Open door between zones	1.6 m^2	0.6	0.5	-	1

@Risk simulations of the moisture production are based on the special conditions of the studying object and data presented earlier in this chapter. The yearly average indoor moisture production for each zone is divided into deciles which each represents 10 fractions of the indoor moisture production. This data is used in the CONTAM model; consequently the result from calculating the indoor moisture supply is given with the same 10 fraction resolution.

10 RESULTS

The subsequent simulations are based on measurements, statistical data and qualified assumptions defined in Chapter 7. The results are presented in diagrams showing the distribution of the indoor moisture production in Swedish single and multi-family dwellings. CONTAM is used to study the airflows between the different zones of the studying object in order to obtain the moisture supply in each of the defined zones of the model.

10.1 Indoor moisture production

Figure 10–1 presents the moisture production rate when making simulations of household compositions in Swedish multi-family dwellings. The results are based on mean production rate per hour and year of simulated family. 10,000 iterations have been performed where every iteration represents a plausible family with statistical variation of Incidence factors, residential floor area and number of persons in the household. According to Figure 10–1, about 35% of Swedish household in multi-family dwellings have an average moisture production rate between 110 to 140 grams of moisture per hour which corresponds to 2.6 to 3.3 kg per day.

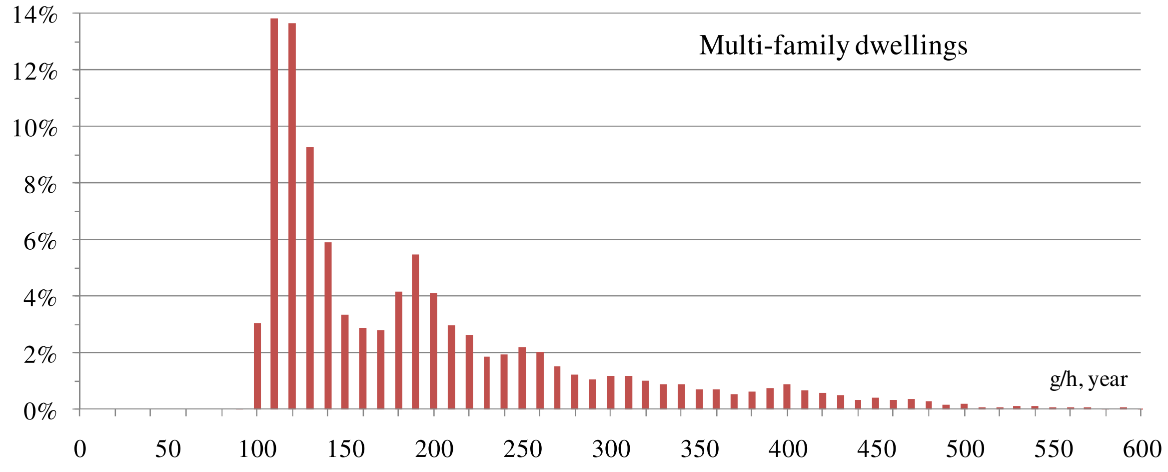

Figure 10–1 The histogram presents the result from simulations of the moisture production in Swedish multi-family dwellings. The moisture production rate is presented as an average rate per hour on yearly basis.The result was given from 10,000 iterations where each iteration represents the yearly mean indoor moisture production from a simulated household in a Swedish multi-family dwelling.

The histogram in Figure 10–1 seems to peak at several intervals of moisture production rates. The main reason to the shape of distribution is the number of household members. The relation is clarified by Figure 10–2 which represents simulations of one, two and three members. Each of the three histograms represents simulations when input data of household members is fixed in the simulation model and therefore have no variation in accordance with statistical data. Except from fixed number of household members, other inputs which have been used in the previous simulation remain.

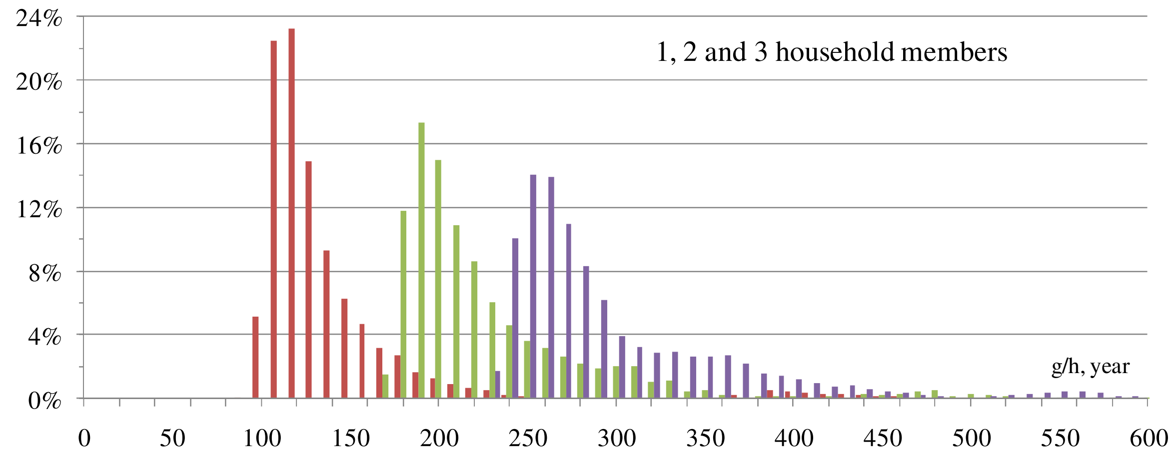

Figure 10–2 The histograms present the result from simulations of the moisture production in Swedish multi-family dwellings.The number of household members are fixed on either one, two or three members and consequently three different distributions are presented. The peaks from the three simulations corresponds with the peaks in Figure 10–1 where the number of household members vary according to statistical data.

Simulation of single family dwellings reveals a distribution curve with similar shape compared to the simulation made on multi-family dwellings. Figure 10–3 presents the mean moisture production rate per hour and year based on 10,000 iterations. Each iteration represents a plausible family with statistical variation of incidence factors, residential floor area and number of persons in the household.

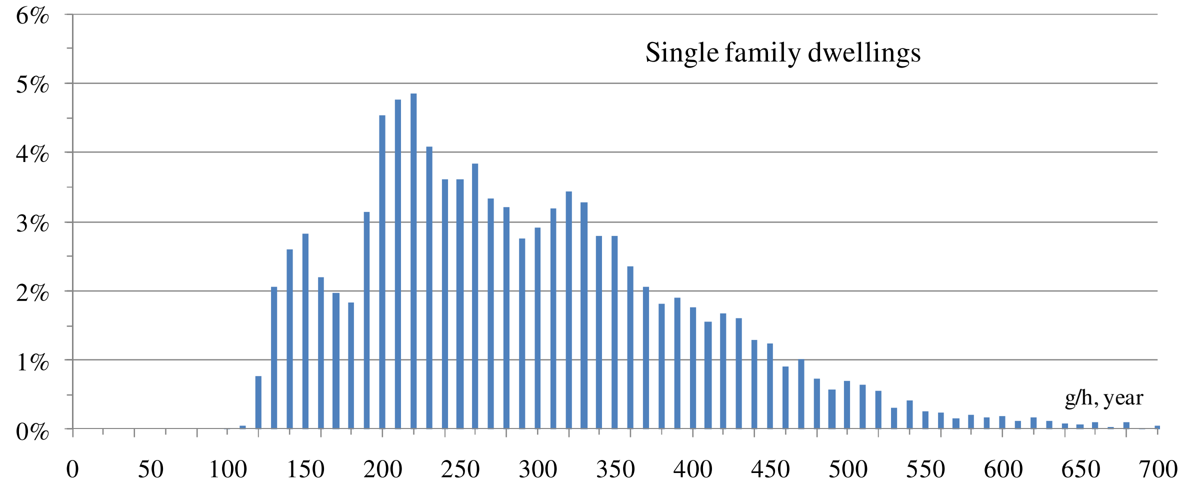

Figure 10–3 The histogram presents the results from making simulations of single family dwellings in Sweden. The moisture production rate is presented as an average rate per hour on yearly basis. The results were produced from 10,000 iterations where each iteration represent a yearly mean value from a plausible composition of a Swedish household in a single family dwelling.

The mean values and variations of the simulations on multi-family and single family dwellings are presented in Table 10-1. The most important aspect when analyzing the results is that they don't present values from a single hour or a single day. Instead they are annual mean production rates from each simulated family with no consideration to time of day or type of month, other than their influence on the mean value and the standard deviation.

Table 10-1 The results from simulations of indoor moisture production due to type of accommodation. The results are presented as minimum and maximum average values per year together with a mean value and a standard deviation of the simulated scenarios.

Total moisture production	**Single family**		**Multi-family**	
	[g/h, year]	[kg/day, year]	[g/h, year]	[kg/day, year]
Mean	298.3	7.16	196.4	4.71
Minimum	114.3	2.74	97.0	2.33
Maximum	896.7	21.52	826.8	19.84
Std. Deviation	110.3	2.65	96.5	2.32

A comparison with field measurements shows some relation with the simulated values of indoor moisture production from this study. According to a Swedish study made in the early nineties, the mean values of moisture production per day were measured to 9.8 kg for single family dwellings and 5.8 kg for multi-family dwellings (Tolstoy, N. *et al.* 1993; Norlén, U. & Andersson, K. 1993). Today the accuracies of these measurements are questioned due to the temperature sensitivity of the measuring equipment (Tolstoy, N. 2010).

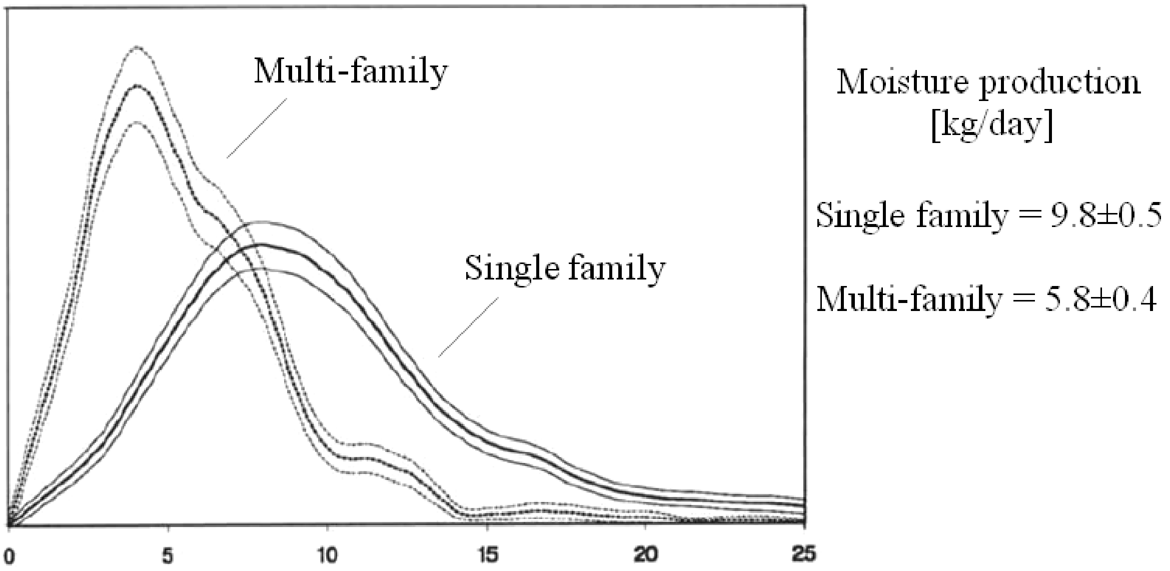

Figure 10–4 The two distributions represents the variation of moisture production based on measurements made in 1,100 dwellings in Sweden between 1991-1992 (Norlén, U. & Andersson, K. 1993). The values presented in the table are daily averages with consideration to year of construction and type of dwelling. The mean values are presented to the right-hand side of the table and with 95% confidence interval.

A recent project named BETSI made by The National Board of Housing, Building and Planning in Sweden presented result from measurements made on 1,800 buildings (Boverket. 2009). The levels of moisture production in this study are much lower than previous studies from the 90s showed. In single family dwellings the mean moisture production per day was 5.1 kg if an average indoor height was assumed to 2.4 meters (Boverket. 2009). Unfortunately, insufficient data was presented in the report in order to obtain moisture production in multi-family dwellings.

A field study made in Finland on 101 single family dwellings present an average moisture production of 5.9 kg per day. Maximum averages per day based on received data during one week and during the winter season was measured to 18.6 and 12.7 respectively (Kalamess, T. 2006).

The contribution from each moisture source depends on the reigning conditions i.e. the scenario which the model is designed to simulate. The five most critical moisture sources are presented in Table 10-2. They are based on annual averages from simulations of 10,000 Swedish families and regardless of type of dwelling. Unvented drying of laundry is estimated to be the most critical indoor moisture source if present. The value of 78.4 g/h in Table 10-2 represents when every load of clothing is dried inside the living. Consequently no drying is being performed with any appliance or outside the indoor environment hence lower values from this activity usually may be expected.

Table 10-2 describes the five most critical moisture sources from simulations but with no consideration to the incidence factor. Both the activity of unvented drying and the presence of aquariums are less common in Swedish households and therefore the contribution from the other three hazards may be considered to be more significant if analyzing the greater part of a building stock.

Table 10-2 The most critical moisture sources in Swedish household if present. The values are based on annual averages and simulations of 10,000 swedish household regardless of type of dwelling.

Moisture production - Top five most critical [g/h, year]		
1	Unvented drying	78.4
2	Humans	72.0
3	Showering	42.1
4	Food preparation - Dinner	38.3
5	Aquarium	35.1

10.2 Indoor moisture supply

The results presented in this chapter are based on the methodology described in Chapter 9 together with the results presented in Chapter 10.1. CONTAM produces the air flows between each zone and between the zones and the outdoor. Figure 10–5 shows the air flow for the different air flow paths in the master bedroom. The ventilation system generates an overpressure in the room which create a driving force for the air flow into the living room and out through the building envelope to the exterior.

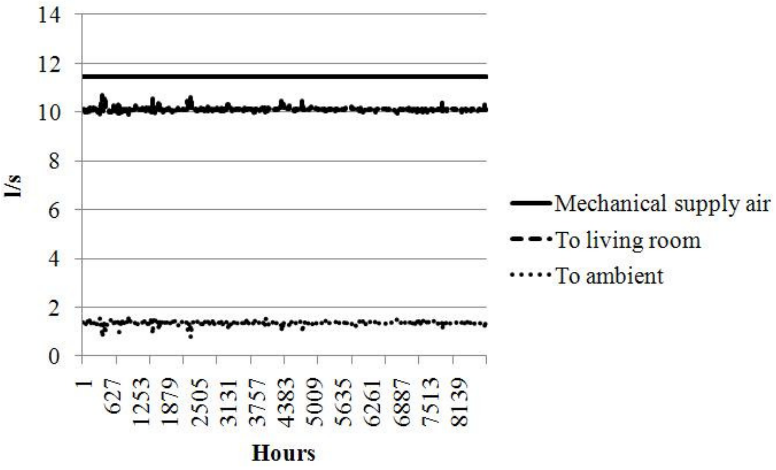

Figure 10–5 Air flows through the master bedroom. The largest air flow is caused by the supply ventilation, which results in air movement into the living room and through the building envelope.

The moisture supply in the three zones living room, master bedroom and kitchen in the studying object are presented in Figure 10–6. The intervals of the moisture supply are changing between the different zones because of the different moisture productions and the air flows between them. The supply air terminal devices are placed in the bedrooms and living rooms and the extract air terminal devices are placed in the bathroom and the kitchen. Due to this reason, the moisture supply is higher in the kitchen compared to the bedroom and the living room. As can be seen in Figure 10–6, the moisture supply varies largely between the different rooms. The figure is based on the 11 cases with linear interpolation of values between these points. Larger sample size would make the curves less pointy.

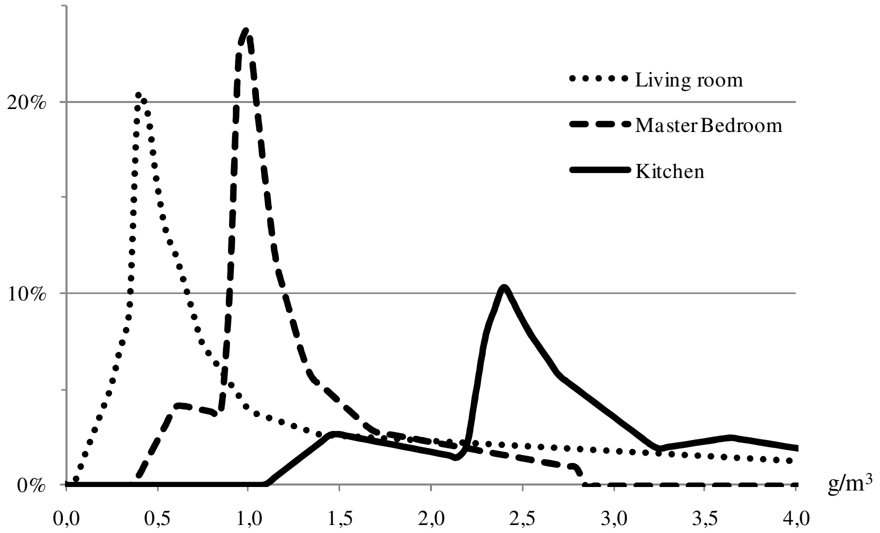

Figure 10–6 Indoor moisture supply based on simulations of moisture production and air flows calculations in Contam for the three zones living room, master bedroom and kitchen. Measurements of the moisure supply are often performed in the living room and bedroom.

Comparing the simulation results to measurements (Boverket, 2009) performed in Swedish multi-family dwellings shows good agreement. Figure 10–7 shows the results of the measurements made in living rooms and bedrooms during October, 2007 to May, 2008. The values in (Boverket, 2009) are similar to the obtained values from the simulations of indoor moisture supply in the living room and the bedroom. Since no measurements were performed in the kitchen, the simulated distribution of the indoor moisture supply in this zone cannot be evaluated.

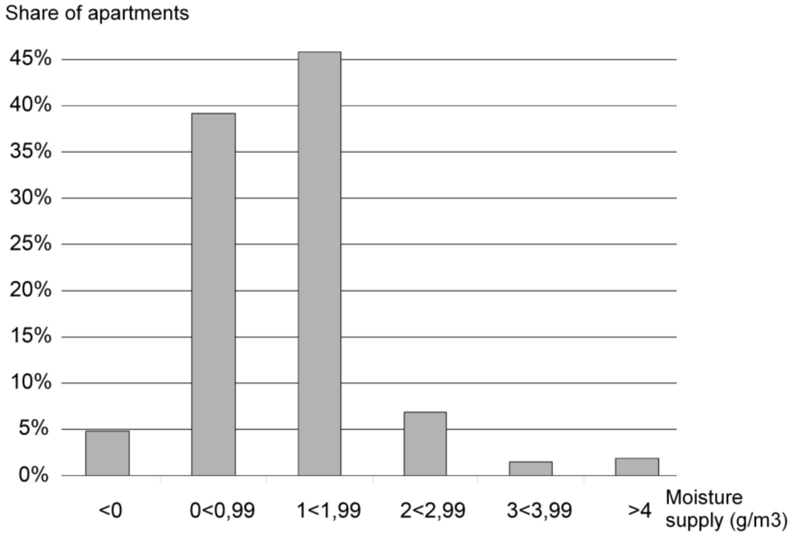

Figure 10–7 Indoor moisture supply in Swedish multi-family dwellings (Boverket, 2009).

11 DISCUSSIONS AND CONCLUSION

This study is using the hazard identification tools what-if, HAZOP, FMEA and VMEA in order to find a risk assessment model which can be applied in the area of building physics. The model starts with a gathering of standards and targets that should be fulfilled by the building. A system analysis is performed of the studying object to be able to find noise factors that influence the variability of the system.

In building physics related problems, it is usually difficult to evaluate all hazards affecting the behavior of the building and indoor climate. Consequently, a general model which may be considered applicable in the field has yet to be designed. It is also difficult to evaluate the interaction between different hazards, since they might influence different parts of the buildings characteristics; e.g. energy consumption, moisture durability and need of repair work. A difficulty when using the hazard identification tools discussed above is recognized by Nielsen (2002) where he recommends to keep the analysis on a higher level and not go into too much detail. The number of noise factors influencing the performance of a building makes it complicated to use classic hazard identification tools (what-if, HAZOP and FMEA).

The simulated moisture production in this study is both lower and higher compared to the two Swedish studies made in the early 1990s and late 2000s (Tolstoy, N. *et al.* 1993; Boverket. 2009). There are some important aspects to consider when comparing the moisture production rates from the field measurements with the ones simulated in this study. The sensors which measure the relative humidity in the measurement studies are placed in the bedrooms and the living room. If the ventilation system works as intended, activities which involve moisture production in areas such as bathrooms and kitchens will have low influence on the received data.

An advantage with the simulation model compared to the previously described measurements is the allocation of each moisture sources. A computer model enables the placement of each moisture source at a chosen position. Consequently the simulation model produces variations of indoor moisture production depending on the space of interest. This is important in order to create credible and plausible compositions of different scenarios for the moisture supply in a random dwelling.

The time between the measurements is also important to consider since there are activities which exists for a short period of time but with a high moisture production rate. Examples of such activities are food preparation and showering. Their total influence on the moisture production may theoretically be underestimated if only measuring once every hour, as for the case of the Finnish study (Kalamess, T. 2006). In the Swedish study BETSI (Boverket. 2009), the sensors received data every fifteen minutes which is probably more sufficient in order to measure the moisture production over time. The disadvantage of the Swedish study in comparison with simulation results is that these measurements were executed during a period of two weeks between October, 2007 and April, 2008. Some of the defined moisture sources are considered to have seasonal variations; hence annual averages will not give satisfying results for these variations. Since measuring during the heating season means that the ventilation rate, thus the effect on the indoor moisture supply, is assumed to be higher due to increased stack effect.

The results from the simulations of the moisture production show great similarity with the measurements presented in Figure 10–4. The reason behind the multiple peaks of the simulated curves was discovered to be influenced by the number of household members. Similar peaks are visible from the measurements of the moisture production in single and multi-family dwellings in Sweden (Norlén, U. & Andersson, K. 1993).

A disadvantage with the approach of simulating the indoor moisture production is the dependence of accurate input data. In this study, no verification has been made regarding the validity of the results from measurements or statistical surveys. Qualified assumptions have been made of the shapes of distributions when no such information was found. The uncertainties depend on the input data and vary greatly between different measurement studies and measuring equipments. In many statistics the 95% confidence interval is applied, although lower levels of confidence intervals are not uncommon. If improvements are to be made on the simulation model, a more directed statistical survey would be of interest. Many of the recommended moisture production rates are based on measurements performed during more than 25 years and therefore their relevance needs to be investigated and in some cases, new measurements might be required.

12 FUTURE RESEARCH

The moisture supply model developed here can be developed further and incorporated with air path simulations in heat, air and moisture simulation toolboxes. Resulting models would make it possible to simulate building parts or whole building assemblies in order to find the weak spots in the construction.

During the statistical data acquisition part there were a large number of blank spots on how much moisture that was generated from certain equipment. Data found was also, in a number of cases, outdated. Measurement studies concerning the moisture generation from different sources would make it possible to in the future refine and make the moisture model more up to date with the living conditions of today.

Simulations of moisture production are performed with hourly resolution and the air flow calculations can also be performed with this resolution. With a network model, the moisture supply in the studied zone can be produced for each hour. Higher resolution of the simulations makes it possible to in detail study the changes in moisture supply between day and night and also annual variations.

13 DISCLAIMER

This document presents results drawn from the Harmonised European Time Use Survey (HETUS) database and table generating tool, but the interpretation of it and other views expressed in this text are those of the author. This text does not necessarily represent the views of the team behind the HETUS database or any national statistical institute which has contributed data to the HETUS database. The author bears full responsibility for all errors and omissions in the interpretation of the output of the HETUS database and table generating tool.

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