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Assessment of performance risks in large atria

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Assessment of Performance Risks in Large Atria

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Colophon

Assessment of performance risks in large atria
MSc Thesis

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ABSTRACT

In this paper a stochastic methodology will be presented and applied to efficiently employ building simulation tools in the risk management process, for a market where there is a need for decision support for risk treatment and selection of assessment tools, especially in Public Private Partnership (PPP) projects. The methodology is directly applied on the PPP-project Renovation Rijnstraat 8 and gives decision support for risk treatment. The application showed that a simple assessment approach already provides guidance towards potential treatment strategies or more complex assessment approaches. Sensitivity analysis and risk evaluation also contribute to the modelling process of defining input parameter ranges and detecting errors in models. Uncertainty of results can be reduced effectively by focussing on influential parameters during the selection of a more complex assessment approach.

1. INTRODUCTION

Risk management is a core element of Public Private Partnership (PPP) contracts, this paper will focus on the management of performance risks for buildings. Risk can be defined as the product of two contributing factors: the probability of occurrence of a threat and its impact or consequence (de Wilde, 2012)(Munier,2014). Risk assessment of future behaviour of systems enables reduction of unwanted conditions leading, for instance, to less efficient operation of systems or undesired indoor climates. The new design for governmental office Rijnstraat 8, in The Hague, has led to the need for assessment of performance risks associated with the indoor climate of large atria. In this project a consortium named Poortcentraal undertakes to design, build, finance, maintain and operate (DBFMO) the building. The assessment of risks in the design stage of this DBFMO-contract is crucial, because Poortcentraal will be responsible for the buildings performance for 25 years. The building features three unconditioned atria, which are orientated South and three semi-conditioned atria, which are orientated North(OMA, 2014).

Atria have been in use with an upward trend for many types of buildings (Bjorn et al, 1997)(Blesgraaf et al, 1996)(Bryn, 1995)(Moosavi et al, 2014).These spaces can be beneficial on multiple levels for the entire building, however, they can also pose risks when considering installation performance and comfort. In particular large atria and their high degree of coupling with the outdoor environment present challenges related to the control of their indoor environment. Common performance risks for atria are downdraught, uncomfortable temperatures and condensation (Schild, 1995). Therefore, the increasing use of glazed atria has also created a demand for assessment of performance risks. Researchers have developed and suggested various methods, ranging from simple (e.g. rule of thumbs and traditional physical calculation methods) up to complex (numerical modelling), to assess thermal and ventilation performance threats of atria. However, the diversity of the modelling approaches makes it difficult to achieve proper conclusions and selecting the right method for the problem (Moosavi et al, 2014) (Morbitzer, 2003). In some cases, increasing the level of complexity of the model may decrease the accuracy of the results, due to increasing uncertainties in the input data (Kolsaker, 1995).

This combination of the need for risk assessment in PPP-projects and the difficulty of selecting the appropriate assessment approach (for large atria) has been the foundation of this paper. The following research question has been formulated:

How can building simulation tools be employed in the most efficient way to support the management of performance risks?

The main objective is developing a systematic methodology to assess performance risks and apply it directly to the previous mentioned case, Rijnstraat 8, concerning the large atria. First, a literature study is conducted and the methodology is developed. Next, this methodology is applied to the case of Rijnstraat 8, where the risk of condensation in the atria is investigated.

2. LITERATURE STUDY

2.1 Risk Management

Some terminology concerning risk management has been introduced already, however, in order to facilitate meaningful discussion it is necessary to give clear definitions. Most definitions are kept in line with ISO 31000:2009, Risk management – Principles and guidelines' and ISO Guide 73 - 'Risk management – Vocabulary – Guidelines for use in standards.' Which are both published in 2009 as an internationally agreed standard for the implementation of risk management principles.

Risk is described as the "effect of uncertainty on objectives". The **risk management** process aids decision making by taking account of uncertainty and the probability of future events or circumstances (intended or unintended) and their impact on agreed objectives. Consequently, the **level of risk** can be defined as the product of probability and consequence as mentioned in the introduction. In the context of performance risk **uncertainty** is expressed as a number of different values that can exist for a quantity (Munier, 2014)(Rausland, 2014)(de Wilde, 2012)(ISO31000, 2009)(ISO Guide 73, 2009).

The risk management framework described by ISO 31000 is shown in Figure 1. First, the context has to be established, subsequently a schematic method for risk assessment. This assessment **identifies** how objectives may be affected, and **analyses** the risk level (probability and consequence), next this risk level **evaluated** whether it is acceptable or further **treatment** is required. The output of risk assessment is a quantified input to the decision making processes of the organization.

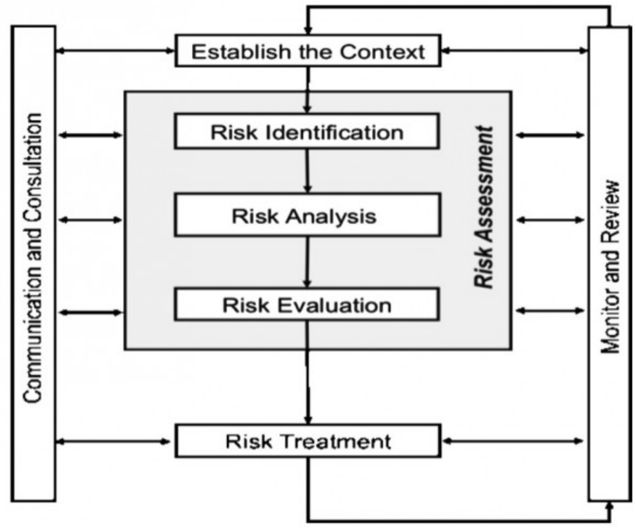


Figure 1. Risk management framework provided by ISO 31000.

2.2 Performance assessment approach

There are various methods available to analyse building performance. Three main approaches to analyse building performance can be defined; Design guidlines or rules of thumb, traditional physical calculation methods and Building Performance Simulations (BPS) (Houben, 2010)(Morbitzer, 2003). This paper will focus on BPS for which the definition of IBPSA (International Building Performance Simulation Association) is used; 'a computer-based, mathematical model of some aspect of building performance based on fundamental physical principles and engineering models.'

- **Design guidelines or rules of thumb**
- **Traditional physical calculation methods**
- **Building Performance Simulation (BPS)**
  - Emperical and Simplified models (steady - state)
  - Single zone model (transient)
  - Multi zone model (transient)
  - CFD or Scale Models

(Houben, 2010)(Morbitzer, 2003)

Above the different approaches are listed in order of increasing detail/ complexity. In practice, there is a tendency to use the most complex approach. The complicated approach will impress the client, however, it will not necessary be more accurate or worth the additional costs of a complex method. How to select the appropriate assessment method remains a challenge (Hensen, 1996)(Kolsaker, 1995)(Djunaedy, 2005). In table 1 the general differences are shown between simple and complex BPS-models.

Table 1 General differences between simple and complex models.

BPS Approach	Simple	Complex
Time	Low	High
Experience	Low	High
Costs	Low	High
Uncertainty	High	Low*

**Sometimes increasing complexity (increasing input parameters) will also increase uncertainty*

When looking from a practical and rationale point of view one can decide to start with the most simple (cheapest and fastest) approach and if that fails (due to high uncertainty) increase the complexity (Djunaedy, 2005). The uncertainty of an approach is the decisive factor whether the complexity level needs to be increased. Uncertainty and sensitivity analysis have been developed to support this decision (Houben, 2010)(de Wit, 2001). First, the uncertainty of all model parameters are estimated based on literature and expert opinions. Secondly, the uncertainty analysis generates the total range of results for all the different parameter values. The sensitivity analysis identifies the parameters which contribute most to the uncertainty (de Wit, 2001).

3. Methodology

3.1 Introduction

Previous research has shown the need of decision support for risk treatment and selection of assessment tools. By incorporating the uncertainty and sensitivity analysis in the risk analysis, decision support will be given for risk treatment and for complexity level of the assessment approach. The accepted level of uncertainty of an assessment is determined by the accepted level of risk for the objective. If the result of an assessment provides a clear answer on the question whether treatment is needed, then an increase of the assessment's complexity is unnecessary. However, when the result is inconclusive about the acceptability of the risk, a more complex assessment is required. Figure 2 shows an example of the risk assessment, where the simple level approach is inconclusive about the acceptability of the risk, due to its large uncertainty. Therefore, the next level of complexity is applied to calculate more accurately i.e. with smaller uncertainty. This level of complexity shows that the calculated risk factor meets the acceptable risk, thus a higher level of complexity is unnecessary. Increasing step by step the complexity level of the simulations will give a more time and cost-efficient approach than making the model too complex.

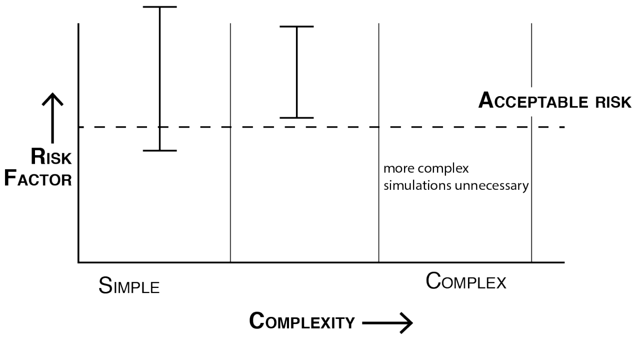


Figure 2. Example of the risk assessment approach.

Figure 3 shows the adapted risk management framework (Figure 1) for performance risks. Where the risk analyses is divided by the two risk factors; consequences and probability, and the loop is created for the increasing complexity.

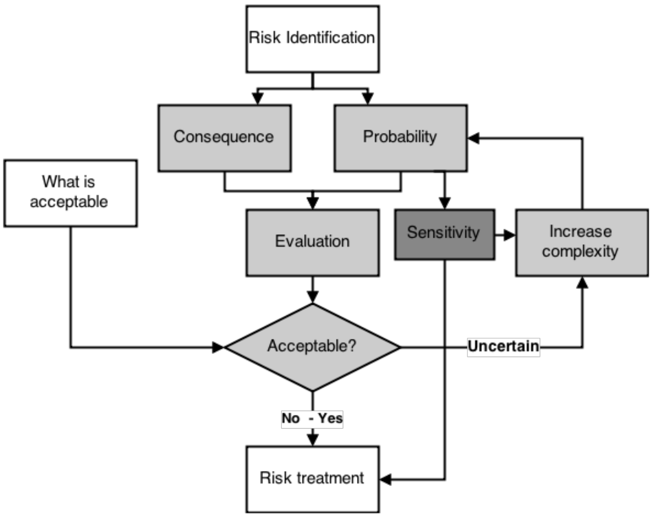


Figure 3. Performance risk management framework.

3.2 Risk Identification

First, the risk has to be identified, the parameters which influence the level of risk and the possible consequences of the risk need to be defined. For example, there is a risk of getting hit by a car if you cross the street. The two basic components of the risk are, the person and the car, whether there is an accident depends among other things on speed, observance and reflexes. A possible consequence can be death or injury of the person getting hit by the car. The key performance indicator (KPI) in this example is, the scale of the injury, which depends on two variables (the person and the car) and the state of the variables depends on other input parameters (speed, observance, reflexes). Figure 4 shows a generic problem identified.

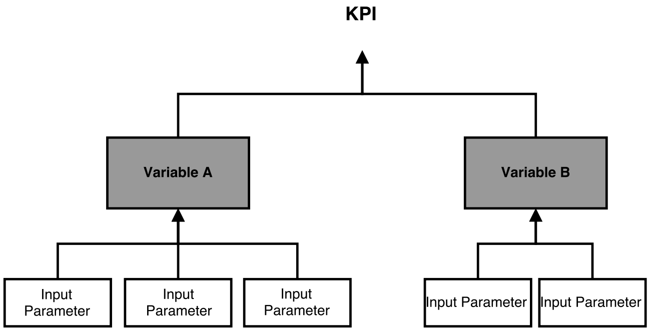


Figure 4. Generic identified problem.

3.3 Consequences

As explained before risk consist out of two factors, consequence and probability. In some cases consequences can be easily quantified by the potential costs it will bring e.g. energy bill, repair costs. In other cases like the example of the accident it is harder to quantify the consequences; how to compare different injuries up to death. In the built environment issues like comfort also are hard to quantify, however, in PPP-projects demands regarding comfort and performance are usually defined in the contracts and when these demands are not met penalties will be given. Thus, the penalties are the potential consequences of performance risks in the PPP-projects, which can be quantified.

3.4 Probability

In deterministic research a set of exact parameters is used (“best case”, “worst case” or most-likely”), which results in a model that will always perform in the same way. Conversely, in stochastic research values are chosen randomly from a range of possible inputs with a probabilistic distribution. Whereas the result of a single deterministic model gives a qualified statement (“if you cross the street without looking, you can get hit by a car”), the result of a stochastic model gives a quantified probability (“if you cross the street without looking, there is 40% chance you get hit by a car”).

Figure 4 shows that the KPI depends on several parameters, however, the exact value of these parameters (on each moment in time) is usually unknown, which results in uncertainty. To quantify the uncertainty of these input parameters a stochastic method can be used. The stochastic method selected to use for this uncertainty analysis is the Monte Carlo method. The Monte Carlo method gives the probability distribution of possible results by running the simulation model for a number of scenarios and randomly selecting a different set of values from the uncertainty ranges of the input parameters. The number of scenarios depends on the uncertainty ranges, the model and the amount of parameters, some guidelines are provided, in previous research, for determining the number of scenarios, however, these turned out to be too unreliable to apply in general (van Goch, 2011)(Hoes, 2007)(de Wit, 2001). Therefore, the amount of scenarios are varied for each model and the median and standard deviation of the results are compared, to verify the minimum amount of scenarios that give a representative probability distribution. The amount of scenarios needed can be quite large and with a large model, the total computation time can become very long. However, Latin hypercube sampling (LHS) can be used to reduce the minimum amount of scenarios needed to achieve a representative probability distribution. LHS is a sampling method, which improves the cover of the input parameters and result. Consequently, less scenarios are needed with the use of LHS.

3.5 Sensitivity

The Monte Carlo method mentioned above gives insight to the influence of the whole parameter set on the probability of the risk. However, if treatment or a more complex simulation appears to be needed, insight of the influence of individual parameters is desired. With the knowledge of the most influential parameters, treatment can be focussed to reduce those parameters or the next simulation method can focus to reduce the uncertainty of those parameters. Moreover, the sensitivity analysis can be used to detect inaccuracies for the ranges of the input parameters or to locate errors in the model. The sensitivity analysis in this methodology consists of Monte-Carlo simulation and linear regression analysis. The latter investigates the relationship between the input and output. Software program SPSS is used to find the standardised regression coefficients (SRC) of the input parameters. The SRC quantifies the changes of the input parameters relative to the output, which means it can be used as relative sensitivity measure (if the input parameters are independent) (Manache and Melching, 2008)(Houben, 2010). The input parameter with the largest SRC has the most influence on the output.

3.6 Evaluation

During the evaluation of the risk, the probability and consequences are combined, and there will be decided whether the risk level is accepted or if the result is too uncertain and further assessment is necessary. Furthermore, the result will be analysed to see when, and for what input values the risk is the highest i.e. the different scenarios and input values are further examined. This analysis will also contribute to the decision for either treatment or further assessment.

3.7 Increase complexity

In this paper the decision for increasing complexity is split up in two choices. Either the original assessment model will be expanded by adding more detail (increase detail), or a new assessment approach is chosen which can take more variables into account (increase variables) (Figure 5). The decision depends on what the most influential input parameters are during the simulation, if the uncertainty range or distribution of an input can be improved by adding more detail in the current model, then a different approach is not necessary. However, when the current model has reached its limits and is unable to take certain effects into account, then a different approach needs to be selected.

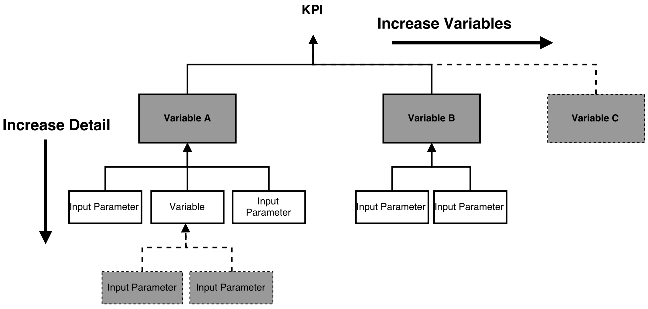


Figure 5. Two ways to increase the complexity of a generic problem

4. APPLICATION

The developed framework is directly applied into practice for a PPP-project, that will function as case-study.

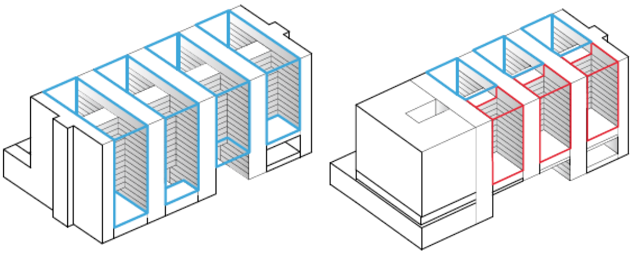


Figure 6 Overview of the original situation (left) and the new design (right) of the case Rijnstraat 8. With the "cold" South atria and " hot" North atria in the new design.

4.1 Case

The performance of the atria of governmental office Rijnstraat 8, in The Hague, will be investigated. The building features three unconditioned atria, which are South orientated and three semi-conditioned atria, which are North orientated. The office building will be renovated in the period 2014 through 2016 (Figure 6). OMA, BAM and ISS, working together in the consortium PoortCentral, have been awarded the PPP- contract for the renovation and maintenance of the former office of the VROM Ministry. In this PPP-contract Poortcentraal undertakes to design, build, finance and maintain and operate (DBFMO) the facility for the duration of the contract. Due to this PPP-contract the assessment of risks is crucial for Poortcentraal, because they will be responsible for the next 25 years. The project, initiated by the Dutch government, will create a new lease of life for the centrally located building, accommodating the Ministries of Foreign Affairs, Infrastructure and Environment, Immigration and Naturalisation Services, and the CAO (Central Agency for the Reception of Asylum Seekers) (OMA, 2014).

For the initial design of Jan Hoogstad in 1993 the demand was that the office windows had to be operable. This demand was a challenge, due to the traffic noise and wind attack at the location. For this reason the atria concept was applied, which functions as noise buffer and blocks out the wind (Perquin et al, 1991) (Ector Hoogstad, 1992). In the new design the building still features six large atria (22.7m x 20.5m x 39.6; 10-12 stories high), as part of the renovation, the ventilation

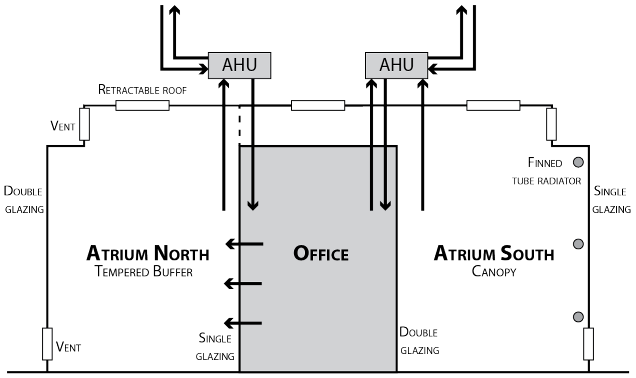


Figure 7. Ventilation principle atria, RIjnstraat 8.

concept for the atria is redesigned. The glass façade of the atria on the North side will be upgraded to HR++ standard. The North atria will be conditioned by balance ventilation air, which overflows from the offices. The offices keep their original glazing. The South atria are 'cold atria' and keep their original façade glazing. Instead, the glazing of the offices adjoining to the atria will be upgraded (Figure 7).

From literature and the original situation of the case-study several potential risks can be identified. The uncertainty of the climate in atria results in uncertainty in energy consumption, moisture content and ventilation efficiency. One of the potential risks concerning moisture is the "condensation" risk during the winter. When it is concluded that condensation is a considerable risk in this research, Poortcentraal still has the opportunity to take preventive measures (risk treatment) in the form of finned tube radiators.

4.2 Risk identification

Fogged up windows and dripping ceilings are undesirable situations which have negative effect on the visual comfort and reputation of the building, furthermore this can lead to complaints from employees. These concerns are the reason for Poortcentraal to investigate the risk of condensation in the atria of Rijnstraat 8.

At every temperature air has a vapour saturation pressure Psat. If the temperature of humid air decreases below a specific temperature (the dewpoint temperature Θdew) saturation will be reached and condensation will occur. The dewpoint is a measure of the absolute humidity (pv = Psat(Θdew). Condensation occurs when the surface temperature in a room drops below the dewpoint. Consequently, key parameters for the risk of condensation are surface temperature and absolute humidity level at the surface (Figure 8). Data is needed to assess whether the risk is acceptable; the indoor air temperature, the moisture release, air change rates, outdoor conditions, and the heat transfer coefficient (Wit, 2009).

Due to low insulation value (single glazing) of the facade and the absence of heating systems there is a possible risk of condensation in the South atria. As the risk is identified the next step will be risk analysis, consisting of two components; consequence and probability.

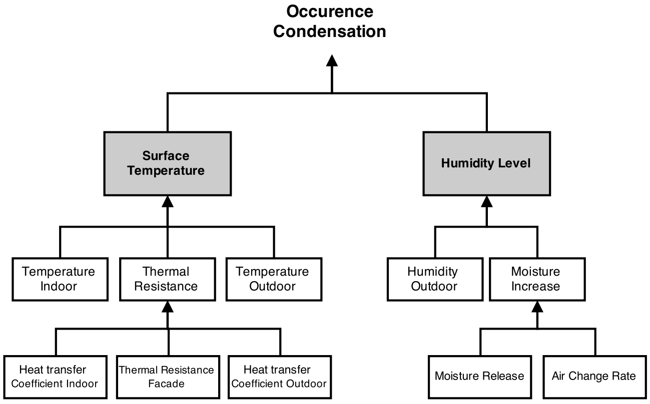


Figure 8. Identification of condensation parameters.

4.3 Consequences

The possible consequences of condensation, as already mentioned, are the negative effect on comfort and reputation of the building. These consequences can be quantified by the use of penalties for unwanted conditions. In the DBMFO-contract, for Rijnstraat 8, penalties and conditions are specified for most spaces in the building. For example, if the temperature in a conference room drops below 21°C for a longer time of 12 hours then a penalty of approximately €200,- has to be paid for each following hour. However, regarding the atria there are no penalties specified in the contract. In order to show the principle of the method and to give an indication of the consequences, some penalties were assumed for the occurrence of condensation (see Table 2). The price per hour rises if the hours are consecutive, which means that if five single hours of condensation occur the penalty will be lower than 5 consecutive hours. The consecutive hours are counted only during office opening hours of 07:00-19:00, this is the same as for the penalties specified in the contract. This also means that if there is condensation from 18:00 till 19:00 and the next day from 07:00 till 08:00, it will be counted as 2 consecutive hours.

Table 2. Assumed prices of penalties for condensation in atria.

Penalties Condensation	
Consecutive hours	Price €/hour
1	5,-
2	7,-
3	10,-
4	20,-
5 or longer	40,-

4.4 Probability

4.4.1 Assessment approach

As described in section 3 the first assessment approach to be selected is the most simple as considered possible. Therefore, the first approach is a simplified model for condensation based on steady-state one-dimensional heat transfer. Matlab was used to build the steady-state model and apply the Monte Carlo method.

As shown in Figure 8 the key components of condensation are surface temperature and humidity level. The humidity level of the South atria is calculated by the sum of the outdoor absolute humidity and the moisture released in the atria, because the atria are unconditioned and defined as canopy the outdoor climate can be assumed as most dominant for the atria's climate (thus also the humidity).

4.4.2. Input parameters

First, all ranges for the input parameters and distributions are defined, due to the simplistic nature of the model and large uncertainty in the aria's behaviour broad ranges were chosen with uniform distribution(Table 3). The values are chosen based on expert opinions, literature and measurements. The value of the thermal resistance of the facade (single glazing) is considered as a constant, because of the low value ($R_{glass} \approx 0.042$ m2K/W).

Table 3. Ranges input parameters

Condensation Matlab M1 - Steady-state			
Input parameters	Unit	Distribution	Values
Temperature Indoor	°C	Uniform	3 - Tout +4
Heat transfer coefficient Indoor	m2K/W	Uniform	2 - 20
Heat transfer coefficient Outdoor	m2K/W	Uniform	5 - 25
Air Change Rate	1/h	Uniform	0.9 - 2.2
Moisture release	g/h	Uniform	0 - 38880

The values of the parameters "Temperature Outdoor", and "Humidity Outdoor" are the most "certain", because the climate and location is known. The values of the **outdoor temperature** and **humidity** are chosen from weather measurements of Rotterdam 2010 (cold year) (KNMI, 2014).

Most of the time the South atria will be unconditioned, however, a minimum of 3°C is specified for the atria's **indoor temperature**. In this simplified model the indoor temperature is assumed to be fully mixed. As mentioned before, the ventilation in the South atria is based on natural ventilation with outdoor air, the atria's absolute humidity will be similar to the outdoors absolute humidity. However, there is a possibility of increasing the humidity by **moisture release** from people and plants in the atrium, and the humid hot air flowing from adjoining offices. Average moisture production for people and plants are respectively 50g/h and 2.5 g/h (Tenwolde et al, 2007). However, the hot humid airflow from the offices is assumed as the most significant moisture source, previous research and simplified calculations showed that the maximum moisture release could be 38.880g/h (Appendix A).

Based on average air-velocities through the vents in the South atria, the range for the **air change rate** is determined. During measurements for the original situation air-velocities were found of approximately 0.2m/s. When assumed velocities between 0.1m/s and 0.25m/s with the vents fully opened, this will result in the range of 0.9/h and 2.2/h for the air change rate (Appendix B).

Two of the most difficult parameters to estimate are the **indoor** and **outdoor** surface **coefficient** of **heat transfer**. The surface temperature strongly depends on these coefficients, especially in this case with the low insulation value of single glazing and the scale of the atria. The air temperature near the ceiling is higher than near the floor, called temperature stratification and due to large height of the atria this difference in temperature, gradient, is even larger than in average sized rooms. These temperature differences can cause downdraught and high flow velocities along the glass facade. Because the indoor temperature is assumed fully-mixed the indoor heat transfer coefficient has been chosen for a wide range and the possible high velocities result in a large maximum convective heat transfer in the atria (the Wit, 2009).

The outdoor heat transfer coefficient consists out of two components, radiative and convective heat transfer. These are combined in one coefficient for the outdoor coefficient. The radiative heat transfer is normally assumed to be approximately 5m2K/w and the outdoor convective heat transfer can reach due to wind a value of 20m2K/w. During clear cold winter nights the roof temperature radiation losses to the sky can become larger than assumed in this model. However, the phenomenon mainly occurs during night time under clear sky conditions, moreover, the simulations are steady-state and run only during office hours. Therefore, this phenomenon is neglected.

4.4.3 Validation

When the original office was designed in 1991 consulting group Peutz also investigated the risk of condensation in the atria using simulations, experiments and measurements in a comparable atrium. Peutz found that the amount of condensation hours would be approximately 20 hours (Perquin et al, 1991). The main difference between the new design and the original situation is the atria's minimum temperature of 3°C instead of 12°C. If the input parameter is changed in the model the result is in the same range as the result of Peutz (See Figure 9, Med= Median, σ= standard deviation, the whiskers represent 99.3% of all scenarios).

4.4.4 Verification

As discussed in section 3.4, the minimum number of scenarios is investigated to verify the results. Due to the relative simplistic nature of this simulation the computational time was short, this made it possible to compare the result of a large amount of scenarios; 10.000 to 20.000. Thus, the use of LHS was unneeded in this assessment. As can be seen in Figure 9 the median and standard variation only show a very small difference, thus 10.000 scenarios is regarded as a representative result for the probability.

4.5 Evaluation

Figure 9 shows the distribution of the condensation hours during office hours per year for the new design, with a median scenario of 290 and min- and maximum from 1 to 1763 condensation hours (without the outliers of the box plot taken into account; outer 0.7%). Which is significant more than the condensation hours of the original situation with the higher atria temperature(Med=19).

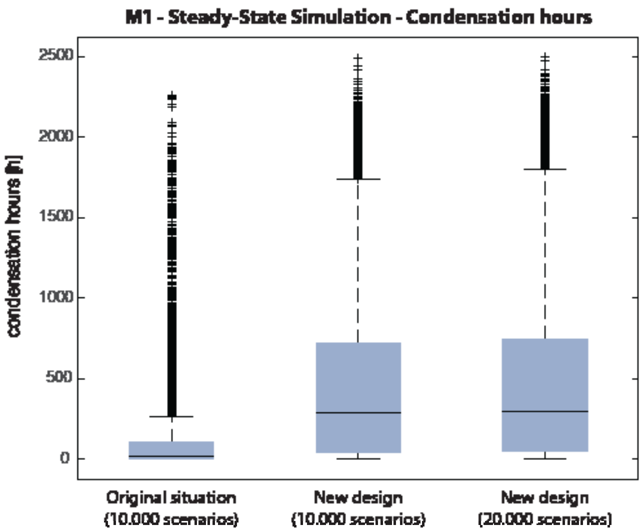


Figure 9. Probability of condensation hours per year during office hours. Including validation and verification. Original situation (Med= 19, σ= 241), New design 10.000 (Med= 290, σ= 516), New design (Med= 295, σ= 516).

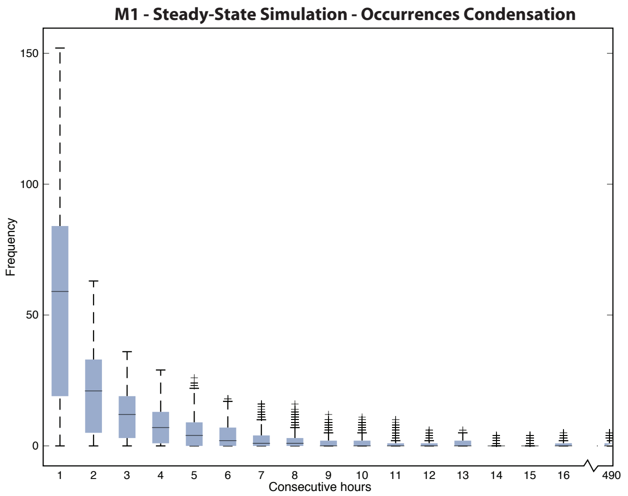


Figure 10. Frequency of consecutive hours of condensation per year. The outliers go up to 490 consecutive hours.

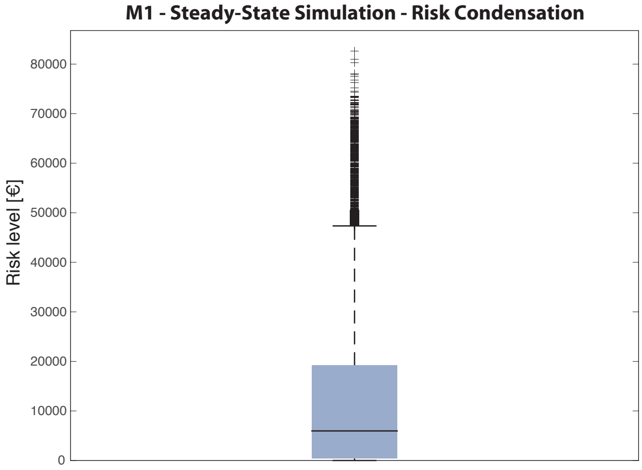


Figure 11. Risk level condensation simulated with simple Matlab (M1) model. M1 (Med= €5.967, σ= €17.095).

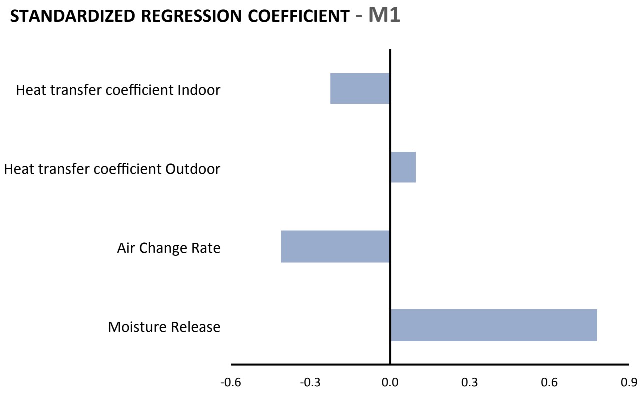


Figure 12. Standard regression coefficient of input parameters.

In Figure 10 the frequency of consecutive hours can be seen, which shows a high frequency of single condensation hours. In outlier scenarios it can be up to 490 consecutive hours, these are also the outliers in Figure 9 with over 2.000 condensation hours. Moreover, this figure is used to calculate the total costs of penalties, which are higher for longer consecutive hours. Figure 11 shows the risk level of condensation, it combines the probability (Figure 9) with the consequences (Figure 10 * Table 2). This gives a median cost scenario of €5.967,- per year, however, Poortcentraal is responsible for 25 years, thus €149.175 and three atria equal €447.525. At this point it is important to state again that the costs presented in this report are fictive, the real costs are zero, because the atria are excluded from the list of spaces with penalties. However, the real "cost" is the negative influence on the reputation of the building and involved companies that is at stake.

The result of the sensitivity analysis can be seen in Figure 12. The input parameter with relative the largest SRC has the most influence on the output. As can be seen in the figure the moisture release has the most influence. The negative value of the SRC means that a larger value of the value reduces the result (amount of condensation hours). Thus, a larger indoor heat transfer coefficient has a positive effect for condensation, and a larger outdoor heat transfer coefficient or moisture production a negative effect. However, the difference of minimum indoor temperature (original situation vs new design) has also a significant impact, this influence can be seen in the large difference of condensation hours between the original situation and the new design in Figure 9 where the only difference of input was the indoor temperature. This parameter could not be taken into account with the sensitivity analysis, due to correlation with the heat transfer outdoor and indoor, and the direct influence on the surface temperature.

If risk treatment is decided to be necessary, then the possible measures should either increase the temperature or indoor heat transfer, or they should reduce moisture production or outdoor heat transfer. However, if the results appear to be too uncertain, an assessment approach should be chosen to get a more accurate temperature of the atrium or a better definition of the moisture release.

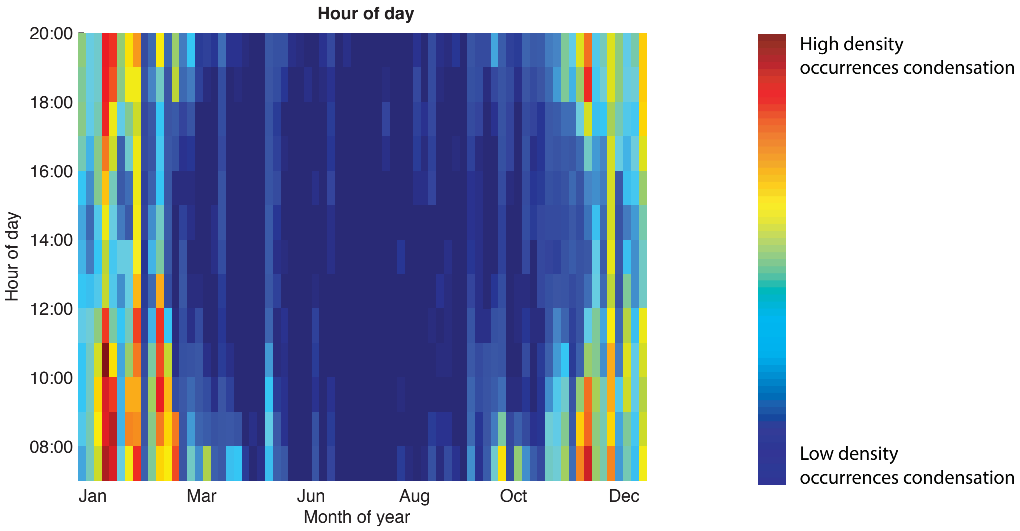
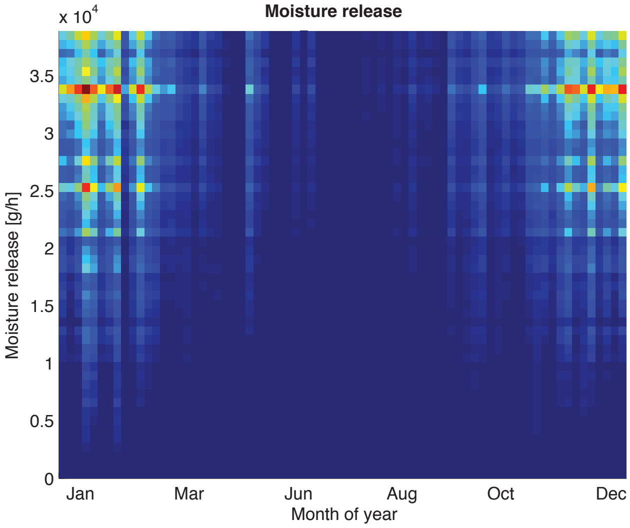


Figure 13. Density occurrence condensation for the hour of the day.



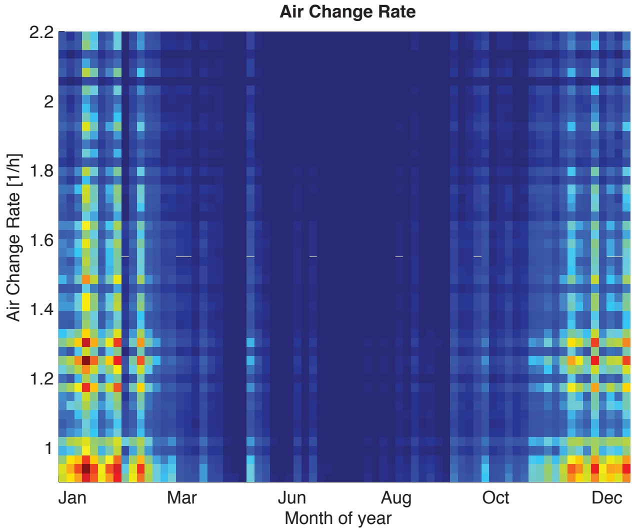


Figure 14. Density occurrence condensation for Moisture release

Figure 15. Density occurrence condensation for Air Change Rate

Figures 13 - 15 show the influence of the parameters and their value more visible and, moreover, they show the situations in which condensation is most likely to occur. The figures give the relative density of condensation occurrences over the year and the corresponding value of the parameter range on the y-axis. The colour scale is relative for each graph, ranging from red, the area with highest density of condensation occurrences, towards blue, areas with the lowest density. Firstly, one pattern in all figures can be seen; during the first days and last days of the year the density of occurrences is the highest. This confirms the expectations that condensation would mainly occur during the cold winter months. Figure 13 shows the hour of the day at which the condensation occurs; the morning hours from 07:00 - 11:00 and the evening hours from 18:00 - 19:00 show the highest density. This result can again be explained by the temperature, which is lower in the morning and evening.

Furthermore, Figure 14 and Figure 15 confirm the result of the sensitivity analysis; Figure 14 shows that a larger moisture release results in a higher density, whereas Figure 15 shows that a smaller Air Chage Rate results in a higher density. An important point is the low density of condensation hours in Figure 14 for the humidity release values between 0 and 2000 g/h, this also confirms the large SRC of the parameter. If the humidity release is reduced or managed, then the condensation hours could be reduced drastically.

4.6 Discussion - Risk treatment or Increase Complexity

The results show that there is a significant increase of condensation hours in the new design compared to the original scenario, due to the decrease of the atria's temperature. Assumed this assessment has proved the risk to be unacceptable, than risk treatment is necessary. Based on the results, treatment could be searched in two directions; ways to increase the surface/ indoor temperature or ways to manage the humidity level. To demonstrate the support this methodology can offer during this process, there are several treatment measures assumed; reduction of moisture release by 25% and 50%, and increase of the minimum indoor temperature by 2°C and 4°C (Figure 18). Both strategy measures show significant reduction of the condensation hours per year. Despite the large uncertainty of the results of the simple model, the effect of treatment measures is still clear. The original treatment for potential condensation was finned tube radiators to increase the surface temperature of the glass, assumed this treatment results in an surface temperature increase of 1°C, then the condensation hours also would be decreased significantly. However, the efficiency of the finned tube radiators in heating the surface temperature is unknown.

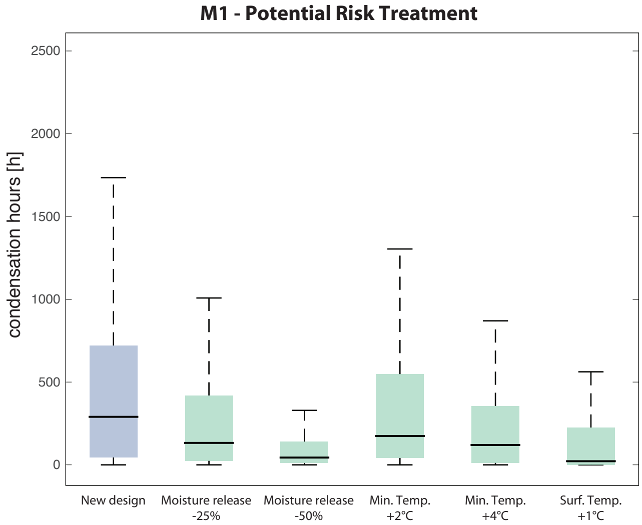


Figure 16 Probability of condensation hours per year for different risk treatments. M1(Med= 290, σ= 516), Moisture release reduction 25% (Med= 133, σ=346) and 50% (Med= 44, σ= 177). Minimum Temperature of atria increase by 2°C (Med= 174, σ= 474) and by 4°C (Med= 120, σ= 407). Surface temperature increase by 1°C (Med= 22, σ= 329).

Assumed these results are considered inconclusive about the acceptability of the risk, more complex simulation methods could be considered. The Matlab model used is steady-state and does not consider humidity release profiles (occupants profiles), or the transient behaviour of the indoor temperature and humidity levels (accumulation and buffering). These elements could be considered in a more complex transient model (transient - single zone model). Furthermore, the atrium's air is considered to be fully-mixed, determining the temperature more accurately and on different locations of the atrium could give a clearer insight of the risk of condensation (transient - multi zone model). An even more complex step would be determining the heat transfer coefficients more accurately (CFD model). Based on the result of Figure 12, the transient single-zone model could be a next step, however, the large influence of the indoor temperature and the possibility of large temperature gradients could also be an argument for directly going to a multi-zone model. A possible solution would be selecting the single-zone model, but taking a range of values for the temperature gradient into account.

Conversely, if is assumed that the risk is accepted, neither treatment nor further assessment is necessary.

4.7 Increase complexity

As explained in the methodology section 3, the complexity can be increased in two ways. One option is by increasing the level of detail and the second option is increasing the amount of variables. The first option is used when the sensitivity analysis shows a large influence for certain input parameters which can be further specified in the original model. The uncertainty of these input parameters will be reduced by adding more details. This will translate to either a smaller input range or a more realistic distribution of the results. The sensitivity analysis showed the moisture release's large influence on the risk of condensation. Thus, detail is added to the parameter of moisture release (Figure 17).

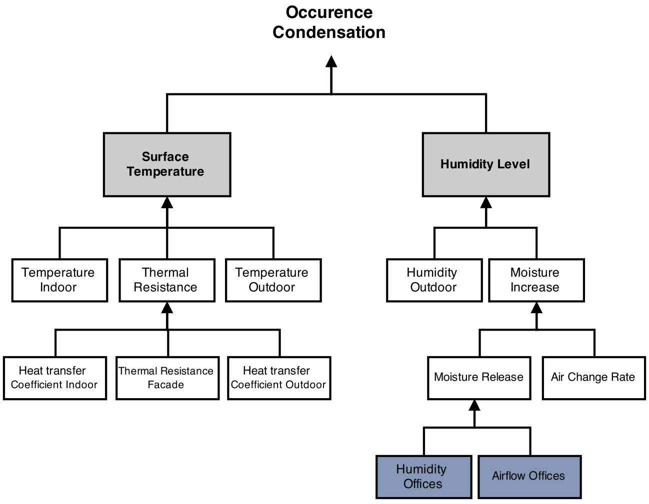


Figure 17. Identification of condensation parameters for M2 model.

The main source of moisture release is the humid air flowing from the offices. By adding the humidity of the offices and the airflow from the offices as new input parameters, the Matlab model is expanded (M2). Table 4 shows the input parameters for M2. The relative humidity of the offices is assumed to be between 25 and 35% during the winter periods, due to the absence of moisture control system in the air handling units. And the airflow is based on previous research and assumed opening rates (Perquin et al, 1991)(Tuohi et al, 2007) see Appendix A for complete calculation.

Table 4. Ranges input parameters M1, M2, T1, and T2 model.

Condensation			
Input parameters	Unit	Values	Model
Temperature Indoor	°C	3 - Tout +4	M1, M2
Heat transfer coefficient Indoor	m2K/W	2 - 20	M1, M2, T1, T2
Heat transfer coefficient Outdoor	m2K/W	5 - 25	M1, M2, T1, T2
Air Change Rate	1/h	0.9 - 2.2	M1, M2, T1, T2
Moisture release	g/h	0 - 38880	M1, T1
Absolute Humidity Offices	g/m3	5.14 - 7.2	M2, T2
Airflow Offices	m3/h	0 - 18750	M2, T2

The second option for increasing the complexity is by increasing the amount of variables. One other influential input parameter appeared to be the indoor temperature, however, the temperature is given as an boundary condition and not calculated in the Matlab model. Therefore, is chosen for a transient assessment approach which calculates the indoor temperature over time. The program chosen is TRNSYS, the main reasons for this choice are user-experience and with TRNSYS it is possible to generate multiple scenarios that are necessary for the Monte Carlo method. These scenarios will be generated with Modefrontier, which has also the option to apply LHS. The LHS is useful in this approach because the computation time of a single scenario in TRNSYS is significant larger than the time of Matlab. The amount of scenarios necessary with LHS has been investigated (Appendix C) and 250 scenarios proved to give a representative result. The ranges of the input parameters for the TRNSYS model (T1) will remain the same (see Figure 19 and Table 4).

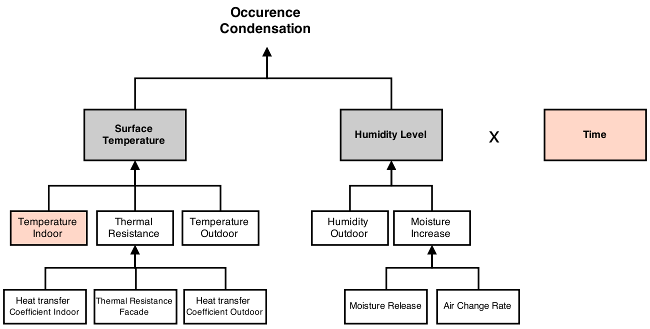


Figure 19. Identification of condensation parameters for T1 model.

In addition a combination model (T2) is made of the two options, thus the T1 model is expanded with added input parameters of the M2 model (see Figure 20 and Table 4). Figure 21 shows a complete overview of the different models and their increased complexity.

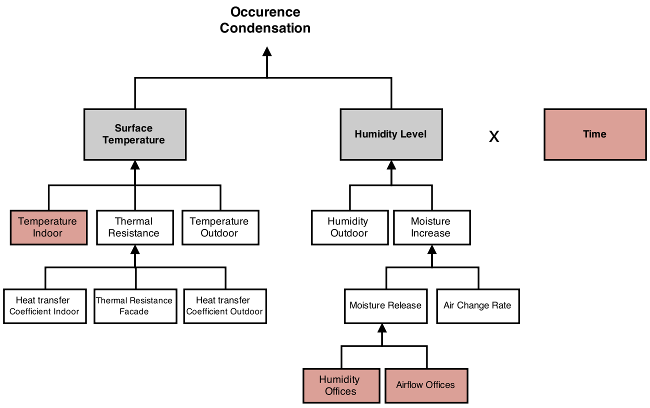


Figure 20. Identification of condensation parameters for T2 model.

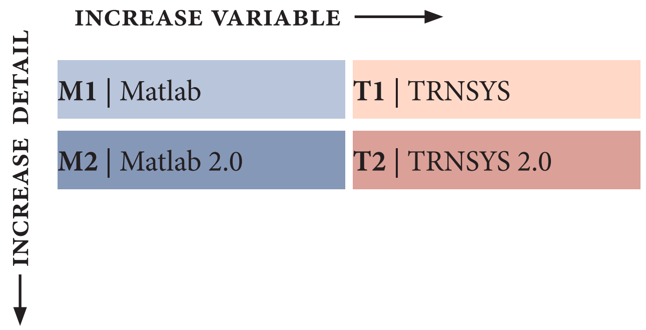


Figure 21. Complexity of M1, M2, T1, and T2.

Figure 22 shows the results for the probability of condensation hours per assessment approach. In general the uncertainty of the result is reduced by the added complexity and focus on the most influential input parameters. The expected buffering effect of a transient approach compared to the steady-state is visible between M1 (σ=516) and T1 (σ=386). The max- and minimum values of the whiskers of T1 are less extreme than those of M1. M2 (Med=135) shows a more skewed box plot compared to M1 (Med=290) and T1 (Med 409), this can be explained by the new distribution for “Moisture release” created by the added input parameters. Further, the interquartile range is larger than M1 or T1, this is the possible result of the short whisker for the lower values and the skewness of the plot. T2 has a significant smaller and lower range compared to the other three (Med=23, σ=110), because TRNSYS also takes into account the heat transfer of the airflow from the offices, whereas the Matlab models only take the moisture transfer into account. This also results in a higher average atria temperature (13.2°C) compared to the more simple T1 model (11.9°C).

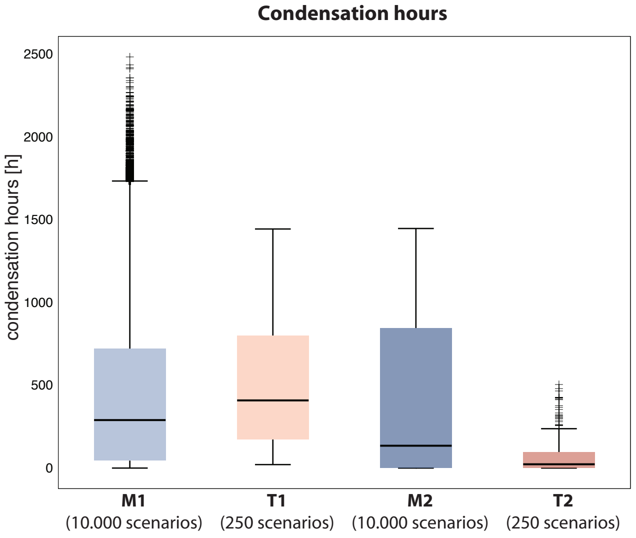


Figure 22 Probability of condensation hours per year for different assessment approaches. (Med= Median, σ= standard deviation) M1(Med= 290, σ= 516), T1 (Med= 409, σ= 386), M2 (Med= 135, σ= 436), T2 (Med= 23, σ= 110).

Another conclusion that can be drawn for this case is that the use of a new assessment model T1 with the same input ranges offers approximately the same range of uncertainty as an expansion of the original M1 model (M2 model). The median value remains in the same range, only the standard deviation decreases, as a difference between the steady-state and the transient approach.

5. DISCUSSION

As seen in the application, this methodology can offer insight in the scale of the risk and provides decision support for selection of treatment and assessments approaches. Although results of simple approaches have large uncertainty they can indicate the scale of potential consequences and probabilities (risk). The simple approach helps to quickly analyse the causes and consequences of a risk.

An important point is the choice of the ranges and distributions of the input parameters. For example, the initial assumption for moisture release was that the moisture production of the people is the most significant moisture source, however, the more complex assessment approaches showed that the hot humid airflow from the offices is a greater moisture source. The moisture release was in hindsight underestimated during initial simulations and this was adjusted to fit the latest assumption to be able to give a clear comparison between different assessment approaches in this report. If a deterministic method was applied the choice of an appropriate single value would even be more difficult, and the effect of that value would be harder to find. The stochastic method in combination with the sensitivity analysis and the density plots opens up the discussion of the influence of parameters on the result. If a parameter shows a very small or very large influence it can be discussed if the ranges are selected appropriately. Moreover, it can also be used to find errors in the model, if certain parameters have unexpected effects it can be an indication that there is an error in the model.

In the application the sensitivity analysis and risk evaluation also offered good guidance for increase of the complexity of the assessment. First, the influential parameters need to be determined, then the question needs to be answered if these parameter's ranges or distribution can be effectively improved in the original model or that a new assessment approach is necessary. Thus, the trade-off needs to be made between the influence of the parameter and how effective the uncertainty of it can be reduced. Moreover, if there is chosen for a new assessment approach the time of making a complete new model should be taken into account as well.

6. CONCLUSION

The developed stochastic methodology presented in this paper shows an efficient way of employing building simulation tools to support the management of risks, for a market where there is a need for decision support for risk treatment and selection of assessment tool. The application showed that the simple assessment approach can provide guidance towards potential treatment methods or more complex assessment approaches. The sensitivity analysis and risk evaluation also contribute in the modelling process of defining input parameter ranges and detecting errors in models. Uncertainty of the result can be reduced effectively by focussing on influential parameters during the selection of the more complex assessment approach.

7. FURTHER RESEARCH

Recommendations for further research would be to use the methodology with more complex approaches as multi-zone models and to take stratification into account. Also, the effect of different weather scenarios or other variations in boundary conditions could be investigated. Further, in depth the effect of different probability distributions (i.e. normal, uniform) for the input parameter ranges could be analysed.

8. ACKNOWLEDGMENT

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Appendix A

Moisture release

1st Assumption

People/ plants as main moisture source

There is a possibility of raising the absolute humidity by moisture production of people and plants in the atrium and adjoining offices. Average moisture production for people and plants are respectively 50g/h and 2.5 g/h (Tenwolde et al, 2007).To maintain simplicity in this assessment the moisture production is seen as one source (people) directly in the atria. The range of people in the atria is based on the amount of people in the adjoining offices and an estimation of the percentage of produced moisture possible transferred to the atria. Thus, when two people are in the office and 50% of the office air is transferred to the atrium, the moisture production is considered to be one person in the atrium.

	value	**unit**	**Reference**
Moisture release people	50	g/h	Tenwolde et al, 2007
Amount of people	350		
Moisture release	**17500**	**g/h**	

2nd Assumption

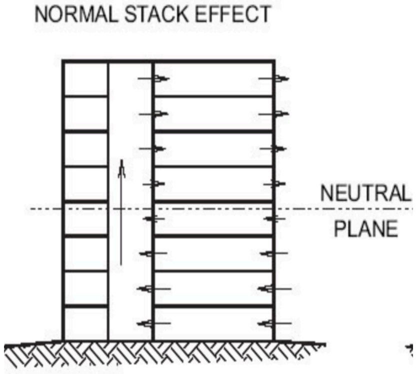
Humid air from offices main moisture source

Based on previous research by Peutz (Perquin et, 1991) on the airflows from the adjoining offices airvelocities could be assumed. In the research was an openingrate assumed of 25%. Now 20% is assumed, because the minimum temperature is significant lower in the atria (3degrees vs 12 degrees). Although, this is still quite large according to other research the openingrate is around 10% during the winter and with an outside temperature of 12 degrees (Tuohy et al, 2007). Due to the lower atria temperatures the maximum airvelocities are assumed higher than the calculations of Peutz.

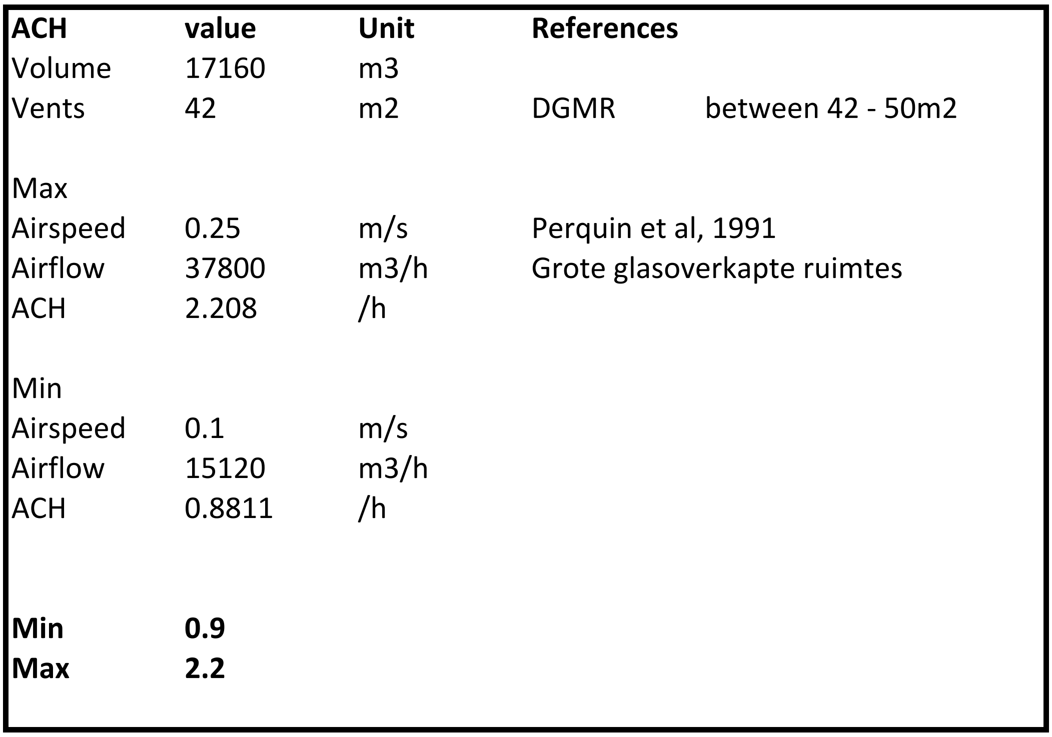
	value	**unit**	**Reference**
Adjoining offices	120		Perquin et al, 1991
Operable window per office	0.5	m2	
Openingrate	20	%	
Airvelocity	0.15	m/s	

Neutral plane is assumed to be in the middle, thus the airflows are dived by half.

Neutral plan	0.5	
Total airflow	**18750**	**m3/h**
RH Offices	25 - 35	%
AH Offices	5.14 - 7.2	g/m3



APPENDIX B



ACH	**value**	**Unit**	**References**	
Volume	17160	m3		
Vents	42	m2	DGMR	between 42 - 50m2
Max				
Airspeed	0.25	m/s	Perquin et al, 1991	
Airflow	37800	m3/h	Grote glasoverkapte ruimtes	
ACH	2.208	/h		
Min				
Airspeed	0.1	m/s		
Airflow	15120	m3/h		
ACH	0.8811	/h		
Min	**0.9**			
Max	**2.2**			

APPENDIX C

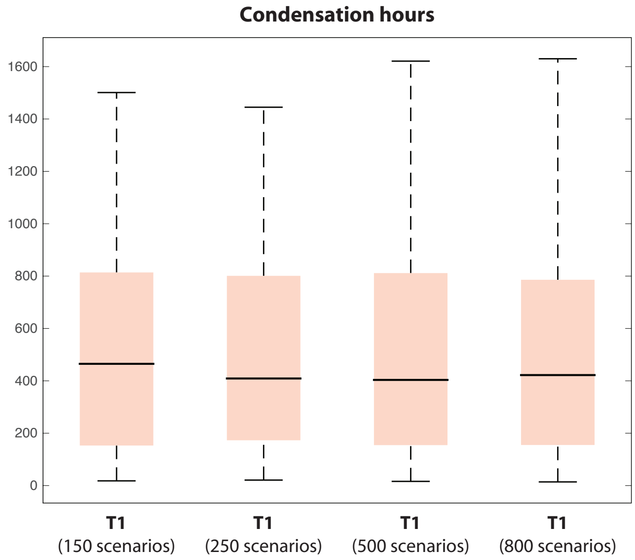


Figure 23. Probability of condensation hours per year during office hours. Verification of needed scenarios for T1- TRNSYS method. T1-150 (Med= 465, σ= 385), T1-250 (Med= 409, σ= 386), T1-500 (Med= 404, σ= 395), T1-800 (Med= 422, σ= 392). Due to the difference in medians, 150 scenarios is considered to be too low. Chosen is for 250 scenarios which has a median and standard deviation in the same range as the higher amount scenarios.

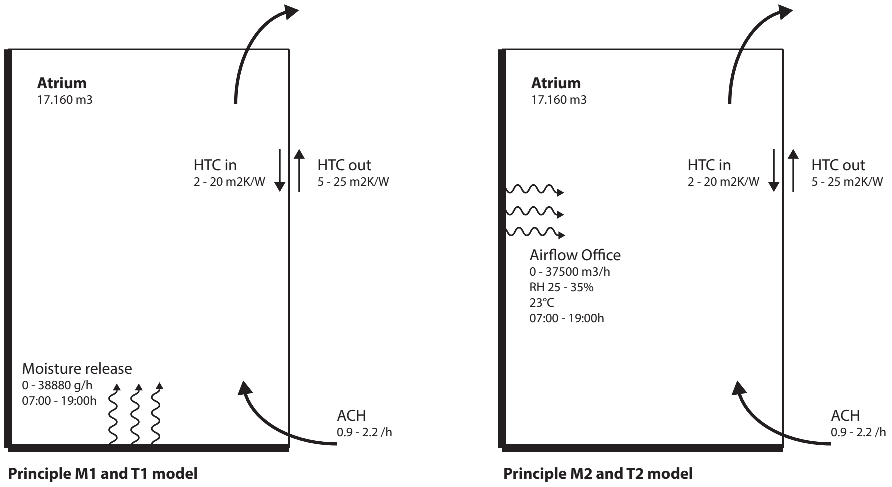


Figure 24. Principles of the different used models in TRNSYS and Matlab

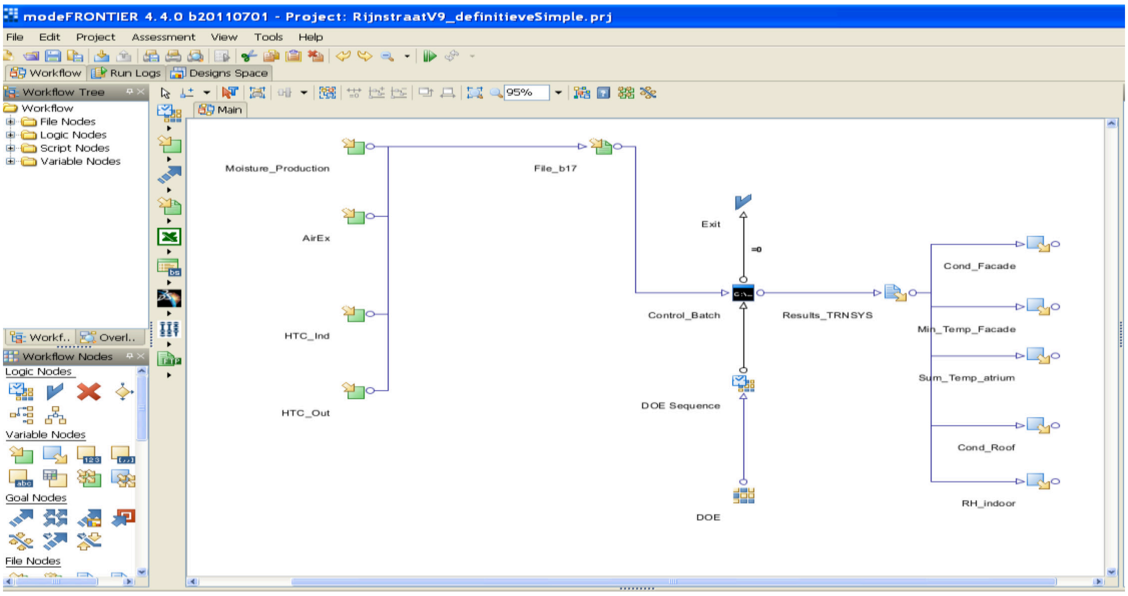


Figure 25. Modefrontier lay-out for T1 - TRNSYS simulations. The other output parameters, besides condensation hours, where used for validation of the model.