SCENARIO ANALYSIS FOR THE ROBUSTNESS ASSESSMENT OF BUILDING DESIGN ALTERNATIVES – A DUTCH CASE STUDY

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ABSTRACT

This paper discusses the use of exploratory scenarios with environmental conditions on a case study in the Dutch context. The goal is thereby to assess the robustness of design alternatives during the lifetime of its building components. During building design it is common practice to use "normative" scenarios to prove compliance with design standards. The use of "exploratory" scenarios is less common. However, it is hypothized that the use of exploratory scenarios is a meaningful alternative, if no information is available on the uncertainty of input data such as climate and building use. This paper focusses particularly on the performance variability due to climate change.

The European Commission targets a 20% reduction of CO_2 emissions, a 20% increase of energy efficiency and a 20% increase in the use of renewable energy by 2020 still providing comfortable conditions within the buildings. As neither, building use nor environmental conditions are constants, it is necessary to quantify their influence on the energy use over the lifetime of its building components and subsequently on achieving the overall aim.

For the designer it is impossible to assess the contribution of his/her individual building project on achieving the goals posed by the European Commission. However, considering the performance of the building and its components under potential future conditions, conditions deviating from the design conditions, has the potential to support design by supporting the selection of design alternatives, provide comfortable conditions and reduce energy demand during building operation. To integrate building use and environmental conditions into the computational performance assessment, their stochastic character needs to be taken into account, which is rarely possible due to limited availability of data. Still, in the absence of stochastic input data the use of exploratory scenarios represents a feasible alternative to map the variability of building use and environmental conditions. The paper concludes that exploratory scenarios present a feasible alternative to assess the future performance of potential design alternatives. Its application on the case study allows to identify the most robust out of three design alternatives by considering the performance indicators energy use and thermal comfort.

Keywords: design support, robustness assessment, performance simulation, climate change, occupancy pattern, future building performance

INTRODUCTION

The assessment of the future performance variability of design alternatives is an important aspect to consider during the design process. The goal is thereby to inform the client and design team about the design alternatives capacity to maintain comfortable conditions throughout the lifetime of the system components but also about its capacity to maintain the balance between energy supply (local generation) and demand as designed.

To integrate building use and environmental conditions into the computational performance assessment, their stochastic character needs to be taken into account. However this information is rarely readily available. In the absence of input data describing the stochastic behaviour the use scenarios represents a feasible alternative to map the variability of building use and environmental conditions onto its performance. It is common practice to use "normative" scenarios as input in building performance studies aiming to prove compliance with building regulations. The use of

"exploratory" scenarios is less common. Exploratory scenarios start with past and present trends, leading to a likely or unlikely future. Following Berkhout and Hertin [1] they are based on four assumptions. (1) The future is not a continuation of the past relationships and dynamics but is always shaped by human choice and action; (2) The future cannot be foreseen; however exploration of the future can inform the decisions of the present; (3) There is not only one possible future, uncertainty calls for a variety of futures mapping a "possibility space"; (4) The development of scenarios involves both relational analysis and subjective judgment.

Mietzner and Reger [2] identify two distinct disadvantages of using scenarios: (a) the necessity to collect expert knowledge and judgment to define comprehensive scenarios, as well as (b) the risk of diverting to wishful thinking, considering the most likely, best- and worst-case scenarios, only. Still, the use of scenarios also has four advantages: (i) potential to consider events with low probability but strong impact; (ii) the possibility of considering different futures side by side; (iii) the potential to recognize "weak signals" for discontinuities and disruptive events; (iiii) they function as vehicle to improve strategic communication about performance. The use of scenarios in building design practice is limited to normative scenarios. However, the robustness assessment of the future performance of design alternatives requires the provision of exploratory scenarios.

METHOD

To investigate the feasibility to use exploratory scenarios for providing design support the authors conducted a simulation study with a number of scenarios representing the projected climate change in the Netherlands across three temporal horizons now, over 15 years and in 30 years. To conduct the study a case study was defined, weather data sets generated and a robustness assessment in between three design alternatives undertaken.

Simulation study

The simulated case study considers one intermediate floor based on the layout of the office tower 'La tour' in Apeldoorn, The Netherlands. For the robustness assessment the performance of three conditioning concepts are investigated; top-cooling, floor cooling and the application of 4-pipe fan coil units. As climate change leads in the Netherlands to warmer and dryer summers, the investigation is limited to the period of April to September [3, 4].

The three concepts are sized to maintain an equal quality of the thermal comfort. The criterion used is zero hours above the adaptive temperature limit (ATL) of 80% for the reference year De Bilt 64/65. The cooling capacity is limited to maintain the target criteria. The concepts are then exposed to reference data sets derived from projected climate data. For the estimation of the uncertainty of the annual cooling, four data sets were used, representing the four change scenarios for the Netherlands W, W+, G and G+. For calculating the uncertainty in the number of hours above the ATL of 80%, 12 data sets were used; the three files 1%, 2% and 5% for each of the four change scenarios.

The *adaptive temperature limits* (ATL) differentiate building types into alpha and beta buildings. The differentiation is based on the degree of influence individuals can practice on their environment. Three performance bands of different quality, which are not to be exceeded, are defined. The central band, class B, indicates an acceptance of 80% of the building occupants over the use period of the building. The innerband, class A, represents the most stringent requirement and indicates a high quality thermal environment with an acceptance of 90% of the building occupants. The outer band, class C, is the most relaxed, only representing an acceptance of 65% of the occupants. Class C is not to be applied to new buildings. Exception can be granted e.g. to historic buildings to limit the technical and financial effort for refurbishments.

The performance bands are defined by the operative temperature and a derivative of the external air temperature; the four-days running mean outdoor temperature (RMOT). The RMOT is calculated from weighted daily means of the current and the three previous days (ISSO, 2004).

Performance indicators

The case study targeted considers the performance indicators the annual cooling demand and the number of hours above the adaptive temperature limit of 80% are applied.

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Future Climate data sets

Data sets generated based on historic weather data are unlikely to satisfactorily describe the external future climate conditions because they cannot account for global warming or cooling and heat island effect to be experienced in the future. To represent climate change in data sets for performance simulation, Guan [5] differentiates four methods: (1) Statistical extrapolation (Degree-day method); (2) Use of global climate models. (3) Imposed offset method; and (4) Application of stochastic weather models.

Of those four methods, the latter two are extensively used in research on building simulation and performance predictions the application of stochastic weather models by e.g., Wilde and Tian [6] and Kershaw [7] and the imposed offset method by e.g., Belcher et al. [8] Crawley [9], Degelman [10], Guan et al. [11]. As there is no information available yet to derive stochastic weather projections for the Netherlands the authors make use of scenarios for the robustness assessment.

Dutch climate change scenarios

The Intergovernmental Panel on Climate Change (IPCC) has formulated a common set of climate change scenarios based on assumptions about the likely future development of energy demand, emissions of greenhouse gases, land use change and future behavior of the climate system. The scenarios are based on results of Global Circulation Models (GCM). GCMs are numerical models for the simulation of physical processes in the atmosphere, ocean, cryosphere and land surface. The models describe the climate using a three dimensional grid with a typical horizontal resolution of 250-600km. Nested regional circulation models (RCM) are used to down-scale the climate change scenarios. Based on input of GCMs and RCMs, the Royal Dutch Meteorological Institute (KNMI) defined four likely climate change scenarios based on two observed phenomena: the global temperature increase and the change in airflow pattern over Western Europe. With respect to the temperature increase, the KNMI distinguishes between a global temperature rise of 1°C and 2°C for the period 1990 till 2050. With respect to air flow pattern, the temperature increase scenarios are associated with more westerly winds during winter and more easterly winds during summer, see Table 1.

Scenario	Global temperature increase in 2050	Change in atmospheric circulation
G	+1oC	Weak
G+	+1oC	Strong
W	+2oC	Weak
W+	+2oC	Strong

Table 1: Parameters values to identify climate change scenarios [12]

With the current knowledge it is not possible to indicate which of the four scenarios is most likely. All four are plausible and are therefore regarded with equal probability for performance simulations.

KNMI'06 Climate scenario data transformation

The KNMI website [13] provides the possibility to transform historic datasets for temperature and precipitation into projected future data sets for a specific location and temporal horizon. The transformation is based on three steps, taking into account the different changes in extremes and mean values over a given period.

Step1: Based on daily means of the standardized historic period the tool calculates the median 10th and 90th percentile for each month of the historic data set.

Step2: The tool determines the deviation of the future climate scenario for the specific time horizon from the historic dataset. The deviation is hardcoded for the horizons 2050 and 2100. Linear interpolation is used for other horizons.

Step3: The historic data series are transformed using the established deviation.

The difference between the projected daily mean air temperature and measured historic daily mean air temperatures was added to each hour of the corresponding day. By repeating the procedure, 20 projected data sets were created for the use with simulation tools. The work was accomplished in close cooperation between VABI BV and the TU/e.

Future projected and reference data sets for the Netherlands

The historic data sets were projected 30 years into the future, 2006 – 2035, using the most extreme KNMI climate change scenario, W+. The 30- year time horizon was chosen as this period corresponds to the expected lifetime of HVAC equipment. Using the projected data four artificial reference data sets were generated by selecting the corresponding months as defined in the NEN 5060. The four artificial reference data sets, one for energy and three for thermal comfort assessment, represent the 30-year projected reference period 1986 - 2005.

Design concepts

The presented simulation study only considered the summer period. That is why heating installation is not represented. The consideration of the system performance and its control in winter and mid-season is not considered.

Top cooling concept is a widely used conditioning concept in the Netherlands. Air is conditioned centrally and distributed over the floors to the rooms. The top-cooling capacity is used to lower the supply air temperature. It does not control the humidity. The supply air temperature is 18°C. However the supply air temperature linearly increases if the external air temperature rises above 28°C. The system maintains a maximum temperature difference between supply air and external air temperature of 10K. The system is expected to be critical with respect to climate change.

The second conditioning concept is *floor-cooling*. The system makes use of pipework installed within the top layer of flooring. Conditioned water is pumped through the pipes to temperate the floor as heat exchanger. The system is modelled to continuously maintain a water temperature of 17°C for cooling and 35°C for heating. Fresh air is provided centrally but unconditioned at the minimum flow rate.

The last conditioning concept considered is the traditional local air-conditioning via 4-pipe fan coils. The fan coil uses convection to via preconditioned air to heat ad cool the space. Different to a 2-pipe the 4-pipe fan coil has different set of supply and return pipes for heating and cooling. The supply water temperature for cooling is 6°C. Fresh air is provided centrally but unconditioned at the minimum flow rate.

RESULTS

Cooling demand

The results in Figure 1 and Figure 2 indicate that for top-cooling an uncertainty band exists which is twice as wide as that for the 4p-fancoil and floor-cooling concepts for the 30 years projection. Whilst it gives the smallest energy demand for the three concepts at 0 years, its mean gives the highest demand over 30 years with an increase of the factor 1.3. The floor cooling and 4p-fancoil concepts initially show a higher cooling demand than the top-cooling concept. However, for the 15 years of projected data the mean for top cooling shows the highest cooling energy demand of the three. The 30 year projections indicate the lowest energy demand for the 4p-fancoil units, followed by the floor cooling concept. Top-cooling gives the highest demand.
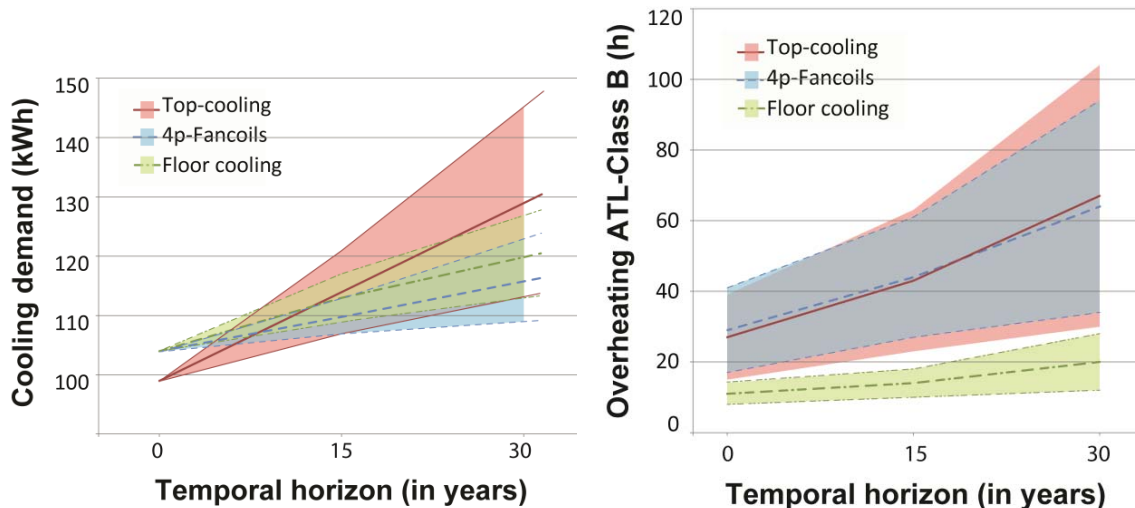

Figure 1: Uncertainty band ($\mu \pm 1\sigma$) of annual cooling demand for two temporal horizons, 15 and 30 years.

Figure 2: Uncertainty band ($\mu \pm 1\sigma$) of number of hours above ATL80% for two temporal horizons, 15 and 30 years.

Adaptive temperature limit 80%

The number of hours above the adaptive temperature limit of 80% shows a different ranking. The least number of hours are indicated by the floor cooling concept with a moderate maximal σ of 8h over 30 years. The uncertainty for the 4p-fancoils and top cooling are 4 and 4.5 times higher, respectively. The uncertainty band for floor cooling does not overlap with the bands for top-cooling and 4p-fancoils.

DISCUSSION

The concepts considered are floor cooling, top-cooling and 4p-fancoils. It was found that the reference data sets from the projected 15 and 30 years provide a good basis for a relative robustness assessment. From the concept comparison it can be concluded that the floor cooling concept provides the most stable and favourable condition with the least uncertainty within the office space during the considered summer period. This information has a high potential to inform the design process and subsequently reduce the impact of the climate on the energy use of the building. Although both diagrams show increasing trends it is not unfeasible that the opposite trend occurs if one takes use pattern and their impact on internal gains into account. The current trend towards lower specific office equipment could potentially offset the impact of the warming climate.

CONCLUSIONS & FUTURE WORK

Scenarios are commonly used in buildings design. It is common practice to use "normative" scenarios to prove compliance with design standards. The use of "exploratory" scenarios is less common. However, exploratory scenarios are required as input to assess the potential future performance of design alternatives as no information is available to quantify their likelihood of occurrence. In cooperation with VABI BV future climate data sets were generated. The data sets

were developed for different temporal horizons. The robustness assessment of three design alternatives shows that the floor cooling alternative performs most favourable compared with the two alternatives top-cooling and 4p-fancoils.

FUTURE WORK

Little is known about the severity of the response of specific performance metrics to the climate data used. Clarke [14] characterized residential buildings using the parameters: capacity, capacity location, window size, infiltration rate and insulation level to categorize typical constructions. Still, the work excludes HVAC system parameters that define the response of integrated building systems to climate variations. Hensen [15] highlighted problems associated with artificial reference data sets. He states that weather parameters, such as temperature, solar radiation and wind, are not necessarily correlated. When selecting days or months to compile an artificial reference data set, the specific applied parameter weights might not correspond to the sensitivities of the building under study. Hensen refers to different building types to illustrate the problem. A building with a high window to wall ratio – type: solar collector - might react most sensitively to variations in solar radiation, whilst a building with no windows - type: repository - is expected to be most sensitive to changes in temperature. As artificial reference data sets are typically purpose bound, e.g. annual energy demand and overheating risk assessment, they need to be carefully chosen for the specific type of performance study and "ideally" also for the type of building at hand.

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