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Evaluation of Daylight Performance in Scale Models and a Full Scale Mock-Up Office

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ABSTRACT: The effective and good daylight design has many challenges according to the dynamics nature of daylight. The best way to improve daylight performance is to take a closer look on the behaviour of lighting the interior of sample building spaces. Scale models are commonly used to assess daylighting performance of buildings using an artificial sky for purpose of research and teaching as well as practice. In this paper the daylight assessment performance of the artificial sky at the Stuttgart University of Applied Sciences, Department of Architecture is evaluated. A method was developed, that allows analyzing the main sources of errors by progressive stages. The field measurements were preformed in a South-South-East faced full scale mock-up office. The four photosensors were placed on the middle axis of test office and scale models and the illuminance was measured from these points. The luminance distribution of the sky and the sun at the time of every single measurement was recorded with a luminance camera and fisheye lens. The measurements were done also with three different façade systems which are Venetian blinds with daylight guiding equipment, horizontal louvres and light shelf. This study is an attempt to identify the main sources of experimental errors occurring in the assessment of building daylighting performance by means of scale models. It is aiming to find a correlation between luminance distribution of the sky and outside direct illuminance and internal illuminance levels and describes a strategy for energy efficient lighting design.

Keywords: daylight assessment, scale model measurements, artificial sky

1. INTRODUCTION

The reduction of building energy consumption and increase of user comfort by means of intelligent daylighting design gain more and more importance.

To achieve these goals, it is essential to assess the daylight performance of buildings in early stages of the design process. Simulation models can be used to asses the annual energy consumption for electric light or the impact of daylight on the thermal behaviour of the building. This is not possible with the analysis of scale models under an artificial sky [1]. But scale models allow an intuitive and direct approach to the given task and working in small groups on the same model. The impact of changes in a scale model can be seen and evaluated immediately, while the impact of changes made in a simulation model has to be recomputed. Depending on the complexity of the building this can take up to some hours or more [2, 3]. Hence the artificial sky is an important tool for the assessment of daylighting performance in early design stages, when geometry and material are not yet defined in detail, and for teaching purposes.

This paper describes a methodology to evaluate the daylighting assessment performance of an artificial and the implementation to the artificial sky at the Stuttgart University of Applied Sciences, Department of Architecture. Unlike precedent studies about scale model measurements this methodology includes measurements in a real test room, of scale models under outside conditions and under the artificial sky [4-6].

2. EXPERIMENTAL METHODOLOGY

The major aim of the methodology is to assess the daylighting performance of scale models in natural and artificial sky conditions as well as to quantify the experimental errors. It allows analysing the main sources of errors in progressive stages by comparing measurements in a test room and scale models under real sky conditions and under the artificial sky.

In a first step simultaneous measurements of work plane illuminance for cloudy and sunny sky conditions are undertaken in a full scale test room and scale models placed under identical outdoor daylighting conditions. The luminance distribution of the sky and the direct horizontal illuminance (in case of direct sunlight) at the time of every single measurement are recorded with a luminance camera and illuminance sensors. In a second step the luminance distribution and the setting for the sun is transferred to the artificial sky and the scale models are measured under reproduced outside daylight conditions.

The measurements were done with models of different scale (1:10, 1:20 and 1:50) and for three different façade systems (Venetian blinds with daylight guiding equipment, horizontal louvers and light shelf). The comparison of the test room and the scale models under the same outside conditions allows isolating and quantifying the errors due to model building, i.e. material and geometry (scale). The comparison of the models under the artificial sky and the same models under outside conditions allows isolating and quantifying the errors due to the performance of the artificial sky, i.e. sky type.

The test room is obstructed by surrounding buildings. To quantify the impact of the external obstructions additional measurements of the scale models are undertaken on top of a high rise building (Max-Kade-Building) near the test room site. Some measurements are also compared to computer simulations with identical settings.

2.1 Test room

The test room is located in an office building near the city centre of Stuttgart, Germany. The two-storey-building is commonly used by the University of Stuttgart and the Stuttgart University of Applied Sciences. The test room is located on the ground floor and facing the parking area. The facade is orientated towards South-South-East (154.5° from North).

The interior of the test room was very inhomogeneous, which would have complicated the model building and caused additional errors in the measurements. Therefore the test room was remodelled. The walls' and ceiling's original surfaces - profiled metal sheeting and timber panels - were covered with plasterboard and painted white. The heavily soiled linoleum floor was covered with a blue-grey carpet; the window frames and the door were painted white.

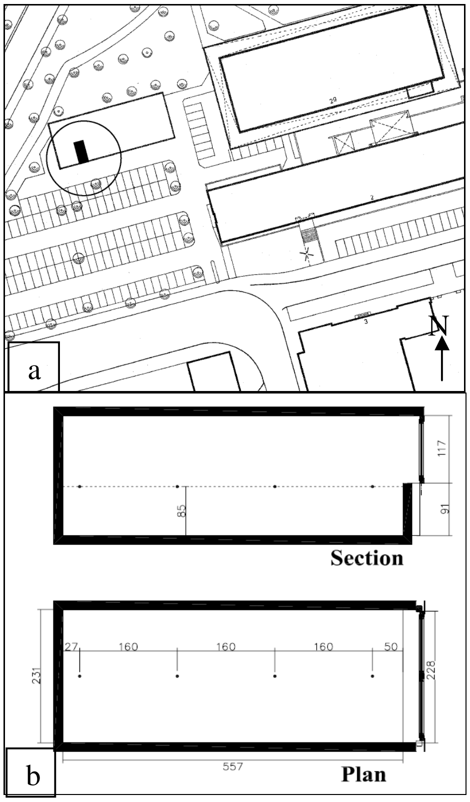

Figure 1: 1a. Site plan (test room in circle) 1b. Floor plan and section of the test room

After remodelling the test room dimensions are 2.31 x 5.84 x 2.08 m (width x depth x height). Floor plan and sections of test room are shown in the Figure 1b.

2.2 Scale models

The scale models built for the measurements differ in scale and material. There are models of the test room and the three façade systems in scale 1:10, 1:20 and 1:50. They represent commonly used model scales for detailed façade (1:10), room (1:20) and building design (1:50).

The glazing of the test room was not modelled. The transmittance of the glazing was measured before every measurement series with a Gossen Mavolux lux-meter. Thus the angle dependent transmittance could be considered as a correction factor in the analysis of the scale model measurements.

The best position for the scale models was the window of the room adjacent to the test room. The horizontal middle axis of the test room window and the scale model window were on the same height. The scale models façade was carefully aligned with the test room façade, but with an overhang of approx. 10 cm to avoid shadowing effects by the façade system rack.

2.3 Sky luminance distribution

The sky luminance distribution was recorded with a TechnoTeam LMK mobile luminance camera and a Nikon FC-E8 fisheye converter. Since the view angle of the luminance camera was restricted to approx. 150° it was not possible to measure the luminance distribution of the whole sky vault with one picture. Therefore a series of four pictures per measurement had to be taken, which took approx. 1 min. 20 second. For transferring the sky luminance distribution into the artificial sky, it was partitioned into 145 regions according to Tregenza´s model [7].

2.4 Illuminance measurement

The illuminance was measured at four points, respectively two points when the 1:50 scale model was used, on the middle axis of the test room and the corresponding points in the scale models. Figure 2 (a) and (b) show the setting in the test room and in a scale model (scale 1:20).

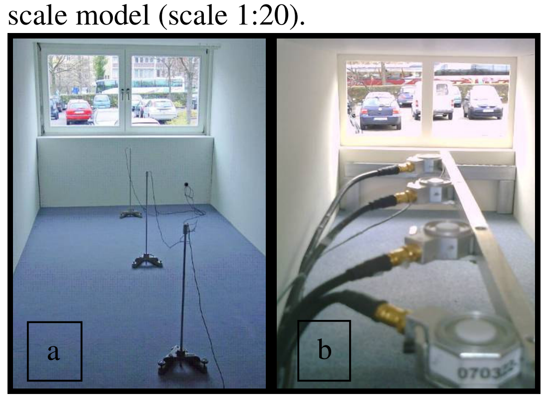

Figure 2: Measurement settings (a) in test room (b) scale model

In cases of direct sunlight on the test room facade the horizontal direct illuminance was recorded and transferred to the artificial sky. This was done by measuring the horizontal total and the diffuse illuminance with an unshaded respectively a shaded illuminance sensor. The difference of these two values is the horizontal direct illuminance.

2.5 Artificial sky and sun

The artificial sky at the HFT Stuttgart has a diameter of 4.20 m. The sky luminance distribution according to Tregenza´s model is simulated with 360 dimmable fluorescent lamps behind a translucent vault. The maximum horizontal illuminance in the middle is approx. 25,000 lux. The sun is represented by a horizontal and vertical movable parabolic mirror with a halogen bulb.

The control system allows setting CIE clear, cloudy, overcast and uniform sky for every time and location. An extension to the control system makes it possible to import measured luminance distributions and set the sun according to measured horizontal direct illuminance levels.

To avoid this, some measurements in the artificial sky were split up into two measurements: one with the sky vault lamps only and higher scaling factor and one with the artificial sun only and low scaling factor. The results were summed up and then compared to the outside measurements

3. EXPERIMENTAL RESULTS

Inside the physical scale models and full scale mock up room, measurements were taken on 4 points (1:10 and 1:20) respectively 2 points (1:50) on the middle axis of the room to evaluate internal illuminance. In this paper, the authors concentrate on the most significant findings of their experiments. The results are dealing with the impact of sky conditions and the impact of surrounding buildings.

3.1 Impact of surrounding buildings

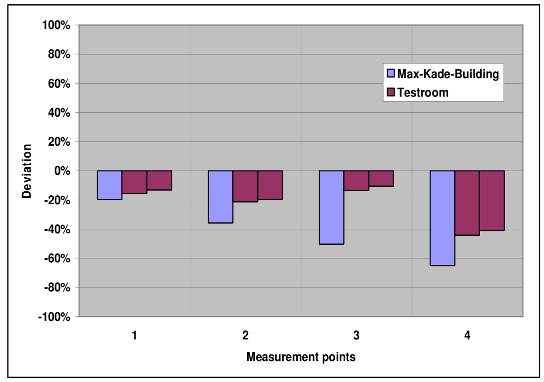

Figure 3: Deviation of illuminance levels between artificial sky and natural sky circumstances comparing the impact of surrounding buildings

Figure 3 indicates a comparison of illuminance measurements in a 1:20 scale model under cloudy sky conditions in the artificial sky and under natural circumstances. The columns show the deviation of the measurements in the artificial sky compared to the measurements under real sky conditions. The first measurement was taken on top of the Max-Kade-Building, i.e. without obstruction affecting the daylight performance. The second and third measurement was taken on the test room site, i.e. with obstruction by the surrounding buildings. While all measurements show an underestimation of illuminance levels in the artificial sky which has the tendency to increase with the distance from the measurement point to the window, the deviations of the measurements with obstruction are lower than in the measurements without obstruction. Since the obstruction is likely to be a serious error source, this seems to be an unexpected result. The “better” results in the measurements with obstruction can be explained by the luminance distribution of the artificial sky. The obstructed sky patches are simulated with a much higher illuminance than measured outside. This is because there are no separations between the sky patches and every sky patch is influenced by the neighbouring ones, even if they are switched off. The higher luminance of the obstructed sky patches is an extra error source, but partly compensates the general underestimation of the artificial sky.

3.2 Impact of sky conditions

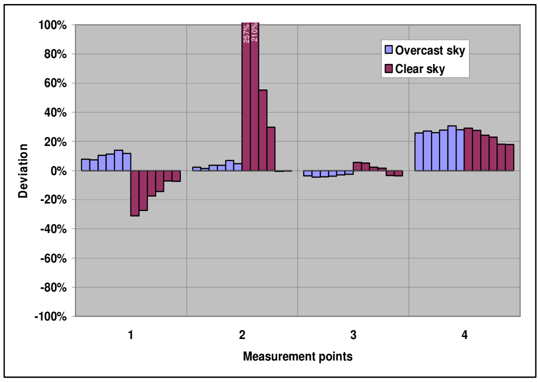

Figure 4: Deviation in natural sky circumstances between the 1/20 model and full scale mock up office comparing the impact of sky conditions

Figure 4 presents the illuminance level deviation between the 1/20 scale model and the full scale mock up room with light shelves under natural sky conditions (cloudy and sunny skies). In cloudy sky, the measurements in the scale model have not much deviation from the full scale room measurements of each measuring point. However, also the illuminance sensor size can influence the illuminance level. Under clear sky, depending on the scale of the model, the sensor can be partly affected by the direct sun light Considering the fact that the illuminance meter dimension is always the same, but the scale of the model may be changing different results may be achieved.

The measurements (Figure 5) between the 1/20 scale model under the artificial sky and the 1/20 model under natural sky with light shelves show, that the trends under cloudy sky are similar, whereas under sunny sky the sun rays strike directly the first measurement point of the model under the natural sky and second point of the model under the artificial sky. If measurements are carried out under a sunny sky in combination with shading systems (here a light shelf is used) measurements will react very sensitive. Especially at the first and second measurement point a significant deviation can be realized.

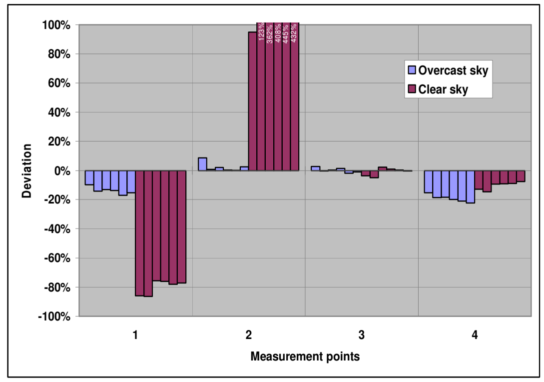

Figure 5: Deviation between artificial sky and natural sky circumstances comparing the impact of sky conditions

4. DISCUSSION AND CONCLUSION

Various experimental uncertainties are involved in this kind of measurements. Since the artificial sky and scale models are used for the assessment of daylighting, errors can not be avoided, but need to be detected and minimized by the development of measurement rules and strategies.

According to the results of this work, experimental errors can be classified into three categories:

- Scale Model Errors: Size of scale models, geometry of model, sensors location, edge joints, colour and material reflection, openings and external obstruction definition [8].
- Artificial Sky Errors: Horizon line error [9], parallax error [10], luminance distribution.
- Luminance Camera Errors: Sky view factor, shadowing effect, analyzing software.

In the scope of this work, several design alternatives were evaluated. The results exposed that the surrounding buildings affect the daylighting distribution within the space. Illuminance level on the measurement points are reduced from window side to the rear of the room without obstruction (Figure 3.). Obstruction show a significant impact on illuminance levels especially between the measurement point 2 and 3.

Moreover, changing sky conditions cause fluctuation in daylighting distribution. This fluctuation is more remarkable under the sunny sky conditions than under cloudy sky conditions (Figure 4 and 5).

In this study, the scale model measurements in natural and artificial sky conditions allow the assessment of the quantity of daylight with different façade systems in different sky types and their transfer into real situations. Openings were modelled accurately in the scale models and to minimize the error glazing was not used. After the measurements a glazing correction factor was used to compare the full scale mock up building and scale models. Some local rules application (like sensor wires pass thought the rear wall) can cause accuracy of measurements problems.

To increase the accuracy and find out the certain problems, more measurements must be taken (in similar and/ or different conditions). Those measurements will be helpful to define errors and find out the correlation between each impact.

Further work is required on comparison of software simulation results and measurements results comparison. According to software simulations, electricity demand (related with daylighting) heating and cooling load will be evaluated.

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