A COMPARISON OF MEASURED AND ESTIMATED ELECTRIC ENERGY USE AND THE IMPACT OF ASSUMED OCCUPANCY PATTERN

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ABSTRACT

The use of building performance simulation (BPS) tools to guide decisions during the design process in its early stages requires making assumptions. That is as the design specification, information about building use and future external climate are not available. This may lead to differences between the buildings performance in operation and its predicted performance. The aim of the presented work is to assess the impact of the building use on observed differences in performance. Parameters of concern are occupation period, occupancy density, electrical energy use and sensible heat gains from equipment and light fittings. The results of the study show that the difference between estimated and measured local electric energy use is below 10%. The important parameters related to the office use are identified as occupation period and heat gains from light fittings. In case of the considered building the use of medium high internal heat gains would have lead to overestimating the cooling demand by 30%. The identified parameters should be considered with great care when using BPS–tools for guiding the design of office buildings as they contribute significantly to the accuracy of simulation results.

INTRODUCTION

Work by others reports differences between predicted performance during design and measured during building operation (Reddy, 2006, Egan, 2009). Assumptions for occupancy density and office use are named to contribute significantly to the observed differences. Reviewed literature indicates a significant impact of parameters related to the representation of internal heat gains in simulation tools and the knowledge about the use pattern. The presented study focuses on quantifying the impact of parameters related to occupancy pattern. Occupancy is typically represented as load imposed on a zone. It is composed of elements as equipment- , lighting gains and sensible and latent heat gains by people. The dependency of the different elements and presence of occupants is rarely considered during design. Instead assumed occupancy schedules are combined with rule-of-thumb-loads for the prediction of the annuals energy demand for heating and cooling. To get an impression about the impact of the assumed occupancy pattern on the electricity demand

measurements and simulation were conducted for an occupied office building. The "BETA-building" located in Amsterdam is a four storey high office building with two wings, A and B, connected by an atrium, see figure 1.
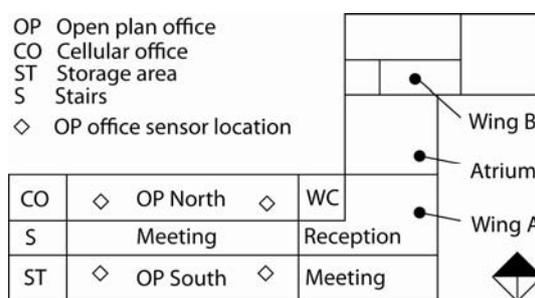

Figure 1 "BETA-building", 4th floor - plan view

The Beta-building is not fully occupied. That is why the study is focused on the top-floor of the building. The top-floor is used by an internationally operating engineering consultancy. The office layout shows a mix of open-plan and cellular offices spaces, meeting rooms, a reception area with access to toilets and coffee machine.

METHODOLOGY

To establish the impact of office use on the difference between predicted and real performance the authors compare real performance and predictions of a number of performance metrics for a four-storey office building in Amsterdam, The Netherlands.

Ideally, one would have the simulation model and its results available from the design phase for comparison with the measured energy use. This was not the case for the case study building. As neither the building model nor its results were available the building was modeled based on the limited extent of still available design information.

In parallel measurements were taken to record the indoor and outdoor environmental conditions. To allow a comparison of the assumed office use during design and the real office use a walkthrough survey was conducted. The aim was to record the present electric internal gains and occupancy pattern.

Subsequently, simulations were undertaken making use of the recorded weather data. Two data sources

options were considered for representing the office use: (1) design reference data and (2) observed data.

In total 106 simulations were conducted. The indoor air temperature predicted for virtual building model was compared with the one measured to gain confidence in its performance.

Finally, the simulation results were converted from energy demand to final energy use for direct comparison with the final energy meter readings.

Measurements

The measurements took place from 23 April 2009 until 1 June 2009. Indoors, the air temperature and relative humidity were measured for individual office units in ten-minute intervals. The recorded variables were transmitted to a central data-logger for later retrieval. Furthermore, the electricity use was read off the local office- and central building electricity meters, once every week. Every space was equipped with one sensor, with exception of open plan office spaces which were equipped with two. They were placed at approximately equal distance from each other and the closest internal partition on the East – West axis. Furthermore, they were set back from the façade to avoid the influence of direct solar radiation. The measurement height was 1.4m corresponding to the head height of a seating person.

Outdoors, the weather variables dry bulb temperature; relative humidity, wind velocity and direction, and global solar radiation were recorded and transmitted to the data-logger.

Walk-through survey

A walk through survey was conducted for the entire building to record levels of occupancy lighting and electrical equipment. The type of equipment, its numbers, and where available name plate ratios were recorded. The missing information was researched making use of relevant publications and manufactures information.

To learn about variations in occupancy and use of office equipment, see table 1, the top-floor offices were surveyed once every hour on four different days of the week. From the recorded data four realistic load profiles were complied for the use with the simulation tool.

Table 1 Walkthrough survey-days of the week

Pos.	Days	Day of the week
1	8 May 2009	Friday
2	12 May 2009	Tuesday
3	14 May 2009	Thursday
4	18 May 2009	Monday

After the first day of the survey it became clear that the people density varied the most during the day from the variables observed. That is why the walkthrough survey was expanded to sub-hourly recordings. The aim was to get an impression about the uncertainty of hourly-based values for occupancy density. Two offices were targeted, the open plan office spaces north and south, see figure 1. For days 2-4, see table 1, the occupancy density was recorded from 10:00-11:00 and 14:00- 15:00 in 15min intervals.

Simulations

Making use of the collected data a virtual model was created and simulated to predict the building electricity use. One module from the VABI Uniform Environment, VA114, was used for facilitating the performance predictions. VA114 is an extensively used Dutch simulation tool. It is dedicated to the analysis of the building energy use and thermal comfort. VA114 has passed the BESTEST and is used in combined activities of IEA Solar Heating and Cooling /Annex 43, Task 34 and IEA Building Community.

Two sets of simulations were conducted (1) making use of the recorded load profiles and (2) using load data form design references.

The use of recorded load profiles is characterized by the uncertainty that the offices can be exposed to one of the four profiles on any one day of the week. To be able to consider the uncertainty the number of possible day-of-the-week and load-profile combination had to be minimized. Two methods were considered Monte Carlo based sampling and differential analysis. The application of a sampling scheme, e.g. Latin hypercube sampling, allows reducing the number of day-of-the-week and load-profile combination. However the differential analysis was chosen as the number of model evaluation could be reduced to two, the maximum and the minimum gains case.

The use of design references required a literature survey to establish...:
1. What values were used during design?
2. How do those data compare with published design guidelines? and…
3. How compare the recorded with the published data?

Finally, simulation runs were conducted with design reference values fir comparison with surveyed sensible heat gain data.

Data analysis

To gain confidence in the performance of the virtual building model, the first step was to compare measured and simulated indoor air temperatures for one un-occupied office unit. The results were compared absolutely, making use and reporting temperature differences, and relatively by observing and comparing their trends.

Once the air temperatures of the virtual building model were assessed sufficiently close to the measured data the energy use for the building and top floor offices were considered. As VA114 provides the energy demand, the simulation output had to be

post-processed to obtain the final energy use. Therefore assumptions were made with regards to the COP for the central cooling installation.

THE BETA-BUILDING AND ITS CONDITIONING CONCEPT

The BETA-building located in Amsterdam is a four storey high office building with two wings, A and B, connected by an atrium. Each wing houses one office unit. The building model for conducting the simulations was constructed based on available design documentation, e.g., the energy performance coefficients (EPC) calculations and floor plans. EPC calculations are mandatory to obtain the Dutch planning permission. The value of the EPC expresses the energetic performance of the design against a notional building. To obtain the planning permission the value of the calculated EPC has to lie below a set threshold.

The BETA-building is equipped with a central ventilation system with pre-heating maintaining a minimum fresh air supply temperature of 18°C. The occupied office units are equipped with fan coil units for heating and cooling. The installed cooling capacity is limited to 25W/m². The buildings heating system is served by district heating.

RESULTS

1. Comparison of predicted and measured indoor air temperatures

To gain trust in the model predictions the predicted air temperatures and measured air temperature were initially compared for an unoccupied office unit and for an occupied office unit. The measured weather data were used for the prediction. Table 2 presents statistics for the measured weather data.

Table 2 Measured data - Weather statistics

	Unit	Min.	Max.	Average
Dry bulb temperature	[°C]	6.3	24.8	13.9
Rel. Humidity	[%]	32.5	97.2	71.6
Wind speed	[m/s]	0.0	14.0	4.8
Global hor. solar radiation	[W/m²]	0.0	939	n/a

Unoccupied office unit

By considering first an unoccupied office space a crude statement could be made about the fidelity of the virtual building model undisturbed by the operation of conditioning equipment, such as fan-coil units, and occupancy pattern. The following points were identified analyzing the measured data:

1. The ventilation system in operating from 9:00 – 22:00 rather than from 7:00 to 18:00.

2. The g-value for the façade glazing is 0.52 instead of 0.34.

The warmest of the four survey days, 14th May, was chosen. The measured weather data were used for the predictions.
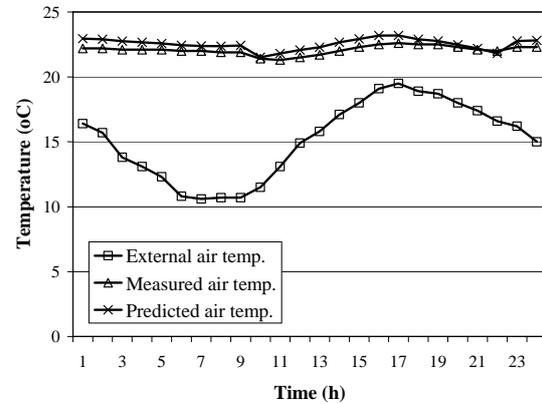

Figure 2 Predicted and measured air temperatures for an unoccupied office unit on the 3rd Floor of Wing A on the 14th of May.

The influence of the ventilation system can be seen for both data sets in figure 2. The difference between the two 24h data sets is on average 0.5K. The averaged difference between the data sets for the entire measurement period is 0.75K.

Occupied office unit

Next, air temperature measurements and predictions were compared for an occupied office unit. Surveyed occupancy pattern and measured weather data were used for the predictions. Figure 1 indicates that the predicted and measured air temperatures compare well for the north-facing open plan office space.
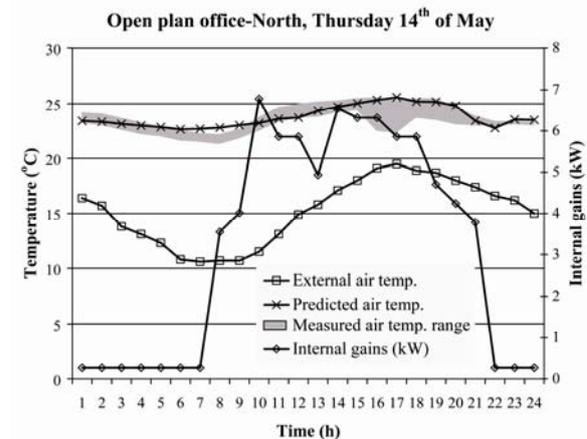

Figure 3 Measured and predicted air temperatures for north-facing open plan office on the 4th floor. Grey area indicates air measurement range by sensor 1&. The internal gains represent sensible gains from electrical equipment, lighting and people.

The indicated error band is due to the measurement data from two sensors. Based on the results it was concluded that the virtual building model performs

sufficiently accurate for predicting the electrical energy use. The good agreement can be attributed to the air-based conditioning concept. The agreement is expected to less favorable in case of a activated thermal mass.

2. Internal heat gains – Walk through survey

A number of observations were made during the walkthrough survey.

1. The office use period differs significantly from the official working hours, 8:30-17:30. People were present from 7:00 till 20:00 on the four survey days. The access lock of the of the Wing A office unit also shows people presence on at least one day in five of six weekends.

2. Office lighting was always on during occupation. It was switched on by the person arriving first and switched off by the person leaving last.

3. A fraction of electrical equipment was running overnight, which accounts for 10% of the electrical equipment gains present during office occupation.

The surveyed internal gains compare with published data for office spaces. The gains surveyed for people and electrical equipment are at the lower end of the scale compared to published design reference data. The lighting gains are with 16W/m^2 well above the 10W/m2 by ISSO (1994) and 13W/m^2 by EN15232 (2007). They lie between the min. and max. values published by Knight and Dunn (2003).

Table 2 Internal gains comparison

	People	Light	Small power	Total
Unit	[W/m^2]	[W/m^2]	[W/m^2]	[W/m^2]
ISSO300	8-10[3]	10	2-35[3]	20-55[3]
Knight[1]	20	8-32[3]	7-45[3]	37-90[3]
Knight[2]	6-30[3]	6-34[3]	6-34[3]	21-86[3]
EN15232	7[5]	13	10	30
Survey[4] (Offices)	5	16	10	32
Survey[4] (Wing A)	3	8	6	17

[1] Composite guidance.
[2] Calculated values based on walkthrough survey.
[3] Minimum and maximum values.
[4] Average from official working hours 8:30-17:30.
[5] From EN15232 (2007), based on 13.3m^2/person and 86W/P sensible gains

Including all occupied spaces of Wing A into the analysis reduces the specific gains to 17W/m^2 corresponding to 54% of the gains recorded in the office spaces during the walkthrough survey. This confirms the shortcomings of using floor area specific internal gains for design. Knight proposes using gains related to occupancy density for design purposes.

The averaged occupancy profiles of the offices were compared with the profile published in the EN15232:2007, see figure 4. The data indicates a one hour shift to the right. It also shows approx. 20% more occupants present in the afternoon compared to EN15232, and approx. 30% of the occupants being present two extra hours in the evening. The employees of the observed office start working an hour later in the morning and work late in the evening.
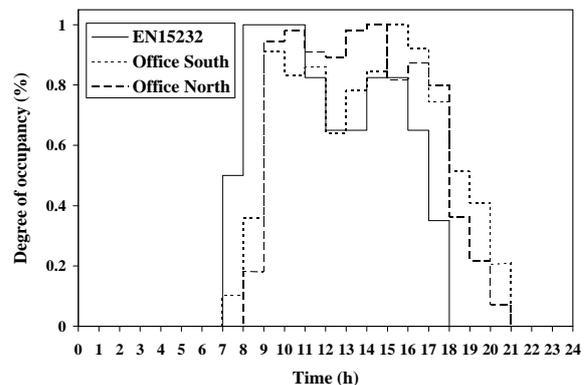

Figure 4 Degree of occupancy for offices, Comparison of EN15232 and observations, Beta-Building, Floor 4, Wing A

3. Comparison of the estimated and recorded electric energy use for the building/ office

The electrical energy use is recorded on two levels, central and local, using conventional electricity meters. The central meter records the use of appliances shared by all tenants, such as building access, atrium lighting, lift, ventilation and cooling. The local electricity meters are dedicated to measuring the electricity use of the individual office units. The local electricity meters measure the electricity use of appliances as fan coil units, computing and communication equipment, light fittings and vending machines, see table 3 for the recorded electricity use.

Table 3 Local and central electricity use (30th of March until 1st of June)

Electricity meter	Unit	Value
Local, Floor 4 -Wing A	[kWh]	7585
Central, Beta-building	[kWh]	34463

Local electricity use - estimation

The data from the walkthrough survey, such as type of equipment, power demand and operating times allows to re-produce the local electricity demand.

The power consumption figures shown in table 3 are based on equipment specific name plate ratios and have been related to floor area. Based on the

calculated data the electricity use of the office unit can be estimated.

Table 3 Estimation of electricity consumption for office unit in Wing A, Floor 4

Gain type	Recorded power consumption	Operation period	Subtotal
	[W/m^2]	[h/d]	[kWh]
Lighting	11.5	13/5	3129
Lighting, other[1]	8	10/5	166
Electrical equipment	6.7	13/5	1812
Electrical equipment, other[2]	0.7	24/7	238
Server + Split unit	1800W	24/7	693
Fan coils [3]	4725W	13/5	990
		Total:	7028

The data presented are averaged data from the four surveyed data sets. The brutto floor area of Wing A floor 4 is 920m^2, and the netto floor area is 837m^2.
[1] Ciculation spaces and toilets.
[2] Communication equipment (telephones, fax, television.)
[3] 29 Fancoil units a 105W.

The estimated local electricity use compares well with the recorded electricity use. The difference between estimation and recording is 557kWh corresponding to 8/%.

Multiple virtual building models were created for the prediction of the cooling demand. At first a building model was created using available design information. This model posed as the "design model". The design model is likely to have been created during the early design stages and is used to produce the "early design stage performance predictions". Further, the earlier presented and "calibrated" building model was used with the measured external climate data and occupancy pattern. It was assumed that the four occupancy profiles observed on the four survey days are representative and equally likely to occur at any day of the work-week.

Two methods were considered quantify the inherent uncertainty. The first, Monte Carlo analysis based approach uses a sampling scheme to reduce the number of possible parameter combinations, which is in our case, $4^5 = 1024$.

Another, the difference based approach only uses the possible parameter combinations expected to give the

maximum and minimum value of the performance metric, which is in our case the cooling demand.

The later has been chosen for the analysis. Figure 5 shows a comparison of the cumulative profiles from the survey spaces on the 4th floor of the Beta-building. Survey day 1 represents the set with the lowest gains and day 4 the set with the highest. Those two profiles were used for the differential analysis.
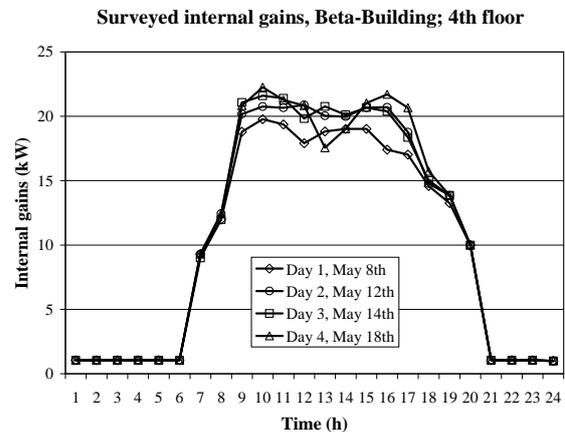

Figure 5 Cumulative gain profiles

By using the internal heat gain data in combination with the assumed and surveyed operating times one can estimate the offices electricity use for comparison with the locally metered electricity. Figure 7 shows differences between the two introduced profiles and design reference data. The difference lies between 1% and 10%. It can be noticed that the difference is the smallest for the design reference data, and the biggest for the low survey gains data set.
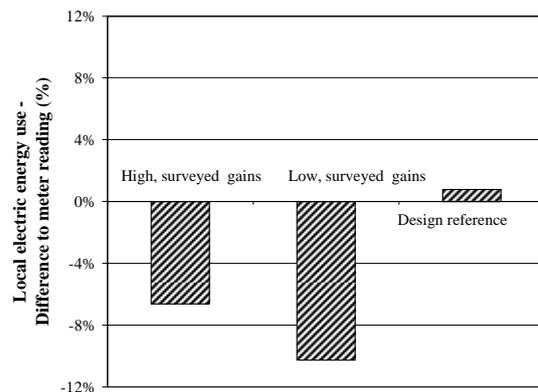

Figure 6 Comparison of local electric energy use from estimations and meter reading, Wing A, 4th floor, Metered electricity use 7585kWh

Prediction of the cooling demand

VA114 was used for the simulations. It was developed to assess the overheating risk and to estimate annual demand and peak loads for heating

and cooling. It does not provide final electricity use figures for cooling, lighting and equipment.

To estimate the electricity use, the recorded occupancy pattern and name plate ratios for equipment and lighting were used. The final electricity use for the roof top chiller was calculated with a published COP of 3.5.

For the prediction of the cooling demand with the "design model", reference data were used. The EPC calculations indicate $12W/m^2$ for artificial lighting. Further based on ISSO 300 (1994), $15W/m^2$ was assumed as sensible heat gains for electrical equipment and $10W/m^2$ for people. $37W/m^2$ represents a medium high internal load for Dutch offices. Building operation was assumed from 8:00-18:00.

Comparing measured and simulated data it was noticed that the fan coils were not operating before Wednesday the 27th of May. The building tenant confirmed the observation stating that the roof top-chiller was switched-off until this date (see Figure A1). Following the observation the simulation period for determining the cooling demand was reduced to 27th of May to 1st of June.

Figure 6 indicates a marginal difference of 3% between the predicted cooling demand using the high and low profile from the surveyed gains profile. However, the difference between the design reference data and the high surveyed gain profile is 34%.
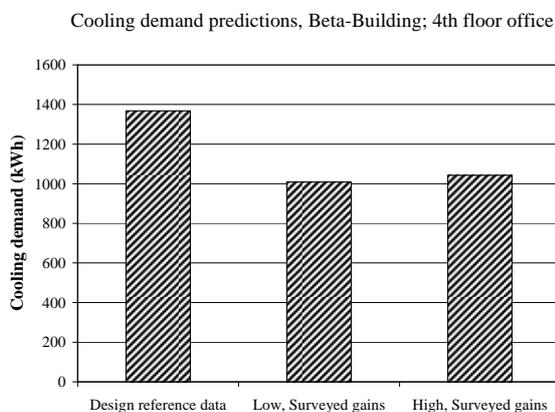
Cooling demand predictions, Beta-Building; 4th floor office

Figure 7 Cooling demand predictions for 4th floor offices; Beta-Building

This suggests that the cooling demand would be overestimated using ISSO 300 medium high internal loads for Dutch office buildings for period considered. That is despite the extended office operation of the real building.

Central electricity use - estimation

To isolate the electricity used by the top floor office units from the central meter reading a number of simplifications were introduced, derived from observations of the building operation and conversations with building tenants:

1. The proportion of electricity used for cooling the top floor office units was determined by converting the predicted cooling demand into final energy use by using a COP of 3.5. This proportion was deducted from the centrally recorded electricity use and added to top floor offices.

2. The remaining centrally recorded electricity was assumed to be the result of shared tenant activities and was divided by four, corresponding to the four floors Thereby the proportion was obtained for which the top floor offices were accountable for.

Based on the introduced simplifications the proportions of electricity used for lighting, electrical equipment, fan coils and cooling can be identified for floor 4 of the Beta-building.
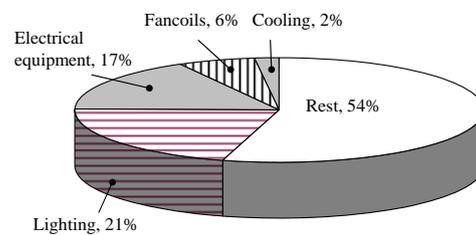

Figure 8 Composition of building electricity use

DISCUSSION

The predicted and measured indoor air temperatures compare well. The good compliances can be attributed to the air based conditioning concept. The compliance would be less favorable if the thermal mass would contribute actively to conditioning the space.

The comparison of predicted and measured air temperature clearly indicated the activation of the roof-top chiller on the 27th of May.

The observed specific gains compare well with published data for offices. It was found that the specific gains by people and electrical equipment are at the lower end of the scale whilst the gains by artificial lighting are medium high.

The occupancy profiles for the office spaces show similar trends to published data but indicate a higher people presence in the afternoon and on average 2h longer working hours.

The estimation of the cooling demand shows that the use of medium high design reference data results in 34% higher cooling demand than predicted by realistic gain profiles with longer working hours.

The presented contribution of the electricity demand for cooling on the measured electricity demand is not representative as cooling was only active for 6 out of 33 days.

CONCLUSIONS

The maximum difference between assumed and surveyed local electricity use was 10%. The figure excludes electricity for cooling.

The prediction of the cooling demand showed a difference of 30% between assumed and surveyed occupancy data. That indicates the potential impact of using accurate occupancy profiles for performance predictions. The results show the importance for carefully considering variables for design such as:

- occupancy period,
- lighting gains,
- always present gains.

During the process of surveying the Beta-building lots of effort was invested on the following subjects:

- gaining access to design information,
- gaining knowledge about the presence, operating schedules and set-points for the individual system components,
- reecognizing clues indicating deviations from design documentation during construction..

Building simulation did prove being a useful tool to recognize system failure states as in the case of the non-operating roof top-chiller.

FUTURE WORK

For future measurements of indoor environmental conditions to calibrate the performance of virtual building models it is recommended to record radiant temperatures. By doing so, it is possible to assess the radiant heat exchange allowing a more accurate modeling of the surface finishes.

Next steps will include the use of Monte Carlo based techniques to estimate the uncertainty of the cooling demand due to occupancy profiles.

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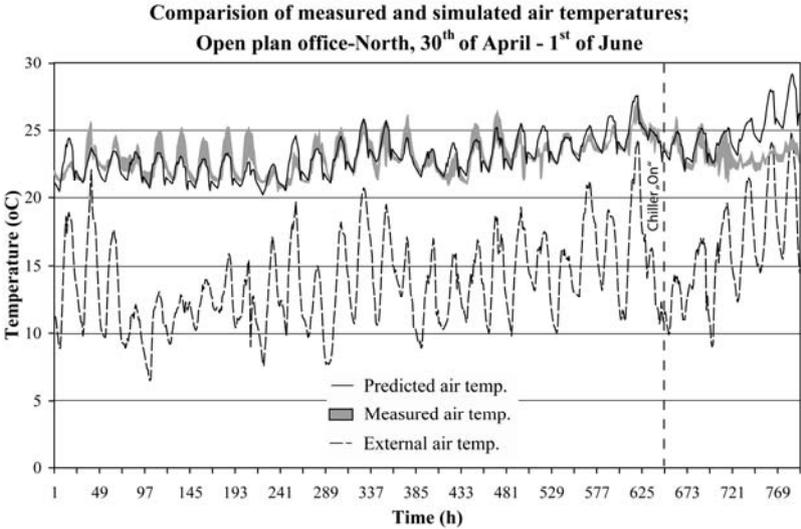
Figure A1 Comparison of measured and simulated air temperatures for the North-facing open plan office space on Floor 4 of Wing A.