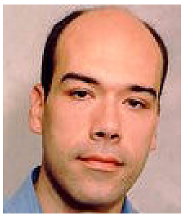
Gemeentehuis Horst aan de Maas: A Case of Excellence in Indoor Environmental Quality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An Indoor Environmental Quality monitoring system developed to be installed in a medium size office building is presented. The architecture of the system, comprising two measuring stations and the building management unit is described, being also addressed the two software tools developed to handle, display, process and analyze the data. Finally, the results of a virtual visit to the building data base are presented and discussed, passing through the different windows available in the visualization software tool.

The main functional purpose of a building is to provide its occupants with safe, healthy, and comfortable indoor conditions. The concept of Indoor Environmental Quality (IEQ), usually defined as the set of conditions associated with the thermal environment, the indoor air quality, the acoustic environment and the visual environment, is normally used to assess the extent to which this objective is achieved in a given building.

In order to keep the values of the physical variables characterizing the indoor environment within the comfort intervals, some energy should be supplied to the technical systems that are installed in buildings to compensate the differences between what the building envelope by itself is able to provide and the target indoor conditions. Optimizing this amount of energy all over the buildings stock is a main goal for the European Union (EU) energy policies, concretized, among others, through the Energy Performance of Buildings Directive (EPBD 1992) and its 1st recast (2010), together with the Energy Efficiency Directive.

There is a statement included in EPBD mentioning that indoor climate cannot be compromised when improving energy performance. However, REHVA (2016) calls the attention, in its position paper, to the fact that most Member States of EU implemented the Directive, through its transcription into the national laws, without paying attention to IEQ. And, if the buildings are not providing good indoor environmental conditions to occupants they are not fulfilling the main function for which they were designed. In addition to the damages that may result in terms of occupant health and comfort, which necessarily have an impact on occupational absenteeism, the productivity of workers in intellectual tasks is also clearly affected if good indoor environmental conditions are not provided.

Hence, achieving, at each moment in time, the appropriate balance between the building's energy consumption and the provided IEQ conditions is a delicate problem that requires a continuous effort in the knowledge and quantification of the two involved aspects. Real time monitoring of energy consumption and of the relevant physical variables together with the calculation of the suitable indices used to assess the indoor environment in the different aspects composing IEQ as the most adequate solution. The Smart Readiness Indicator (SRI) concept has been recently launched in the 2nd Recast of EPBD as an optional common European Union scheme to indicate how smart a building is. It is stated that the rating shall be based on the assessment of the building's or building unit's capabilities to adapt its operation to the needs of the occupant, and the grid, and to improve energy efficiency and overall performance, where indoor environmental quality should be included.

In this article, the efforts conducted in the framework of the retrofitting process of Gemeentehuis Horst, the 7.600 m^2 town hall building of the Municipality of Horst aan de Maas, in The Netherlands, to transform it in a case of excellence in terms of IEQ, are reported. The renewal of a substantial part of the HVAC systems in the building implied the writing of a set of IEQ performance and systems concept specifications and in the process of drafting these, the requirements alone were considered to be inadequate in terms of quality assurance. Thus, has been added to the scope of work a two-year Soft Landings program for objectively assessing and evaluating the real IEQ achievements before a final and formal completion could be established. The work was carried by a partnership where the Dutch consulting company Van Cappellen Advies worked together with a team of researchers from the Mechanical Engineering Department of the University of Coimbra, in Portugal and with the technical staff of the Horst municipality.

Experimental Measuring Chain

The monitoring development project started in 2014 and its main objective was again to install a monitoring system, able to assess the IEQ conditions of the building (**Figure 1**) in the various aspects contributing to the human perception of comfort (thermal, acoustic and

Figure 1. The Gemeentehuis Horst building.

visual environments together with indoor air quality). Besides the measurement of the relevant environmental variables, another feature requested for the system to be installed has been the calculation of the indices commonly used for a more holistic assessment (e.g. the operative temperature, the predicted mean vote (PMV), the predicted percentage of dissatisfied (PPD) and the noise equivalent level (Leq)).

Into the project's performance and concept specifications is incorporated the thermal adaptive model ATG for a Beta type building/climate according to Dutch topical trade publication ISSO-74:2014, Thermal Comfort . In both Fanger's thermal comfort model (ISO 7730:2005), as well as in the adaptive model (EN15251:2007; ASHRAE 55:2013), the Operative Temperature T_o plays a key role, notwithstanding the fact that building management or control systems only operate on the basis of ambient room air temperature and not at local workplace level.

The initial main technical requirements for the project were:

- Develop a mobile indoor measuring station unit for the evaluation of work place conditions;
- Develop an outdoor sensor station unit, in order to be able to relate the indoor environment to the outdoor environmental conditions;
- Develop a base unit that collects, processes, and computes the relevant descriptors and indices and stores the streaming data in the form of data files per day;
- Develop a presentation/dashboard system that visualizes the measured and calculated real time values at a pre-defined time interval (default value: 5 minutes) and facilitates professional analysis and report making;
- Data communication, either cabled or wireless, should be completely independent from any corporate infrastructure;
- Hardware, sensors in particular, must be commercially available on the market and have a digital output readable through an USB port;
- Software is specially developed into a modular, adaptable concept, which makes future changes easily possible. Widely used software platforms are to be preferred.

The developed system (**Figure 2**) consists of four major hardware parts:

a. Mobile sensor station, named WP from the initials of work place
b. Fixed outdoor sensor station
c. Base station
d. Building manager's station

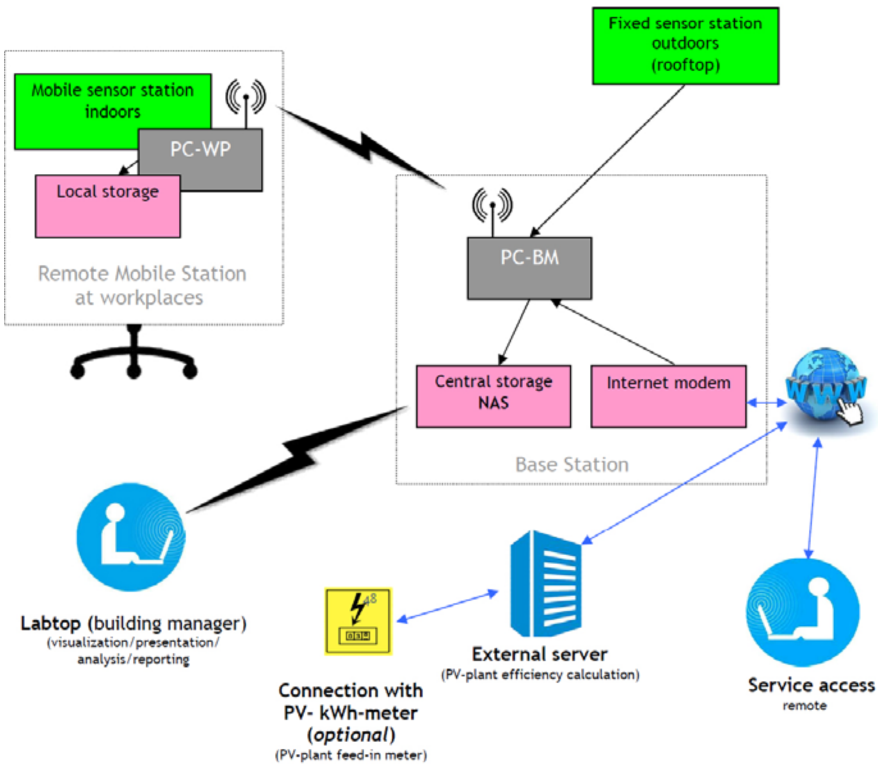

Figure 2. Architecture of the developed monitoring system.

The mobile station can be put freely at each workplace; only the 230 V power has to be plugged in; the power supply when commuting from one work place to the other is assured by an UPS to avoid losses of data. It is equipped with sensors to measure the following variables:

- mean radiant temperature (black globe);
- air velocity/temperature/barometric pressure, at the neck position;
- air velocity/temperature, at the ankle position;
- surface temperature distributions of floor/ceiling/wall-window;
- relative humidity;
- sound pressure level (A weighted);
- Illuminance level;
- Concentrations of CO_2, VOCs, and particle matter PM10, PM2.5 and PM1.0.

Sensors to measure the following variables are mounted in the fixed outdoor station:

- air temperature;
- relative humidity;
- barometric pressure;
- wind velocity/direction;
- solar irradiance;
- concentration of CO_2 and fine particle matter PM10, PM2,5, PM1.0.

The wind and solar sensors are mounted on poles at 5 m+ roof level; the other sensors inside and onto the station's enclosure. Sensors are resistant against common Northern European operational winter and summer conditions (–10°C to 40°C; high humidity levels).

The building manager's station is a laptop on which presentation/dashboard software runs and with which analysis and reports can be made. The laptop has a wireless streaming data communication with the base station.

The sensors produce raw data and processed data generally each 0.1 s, of which a 5 minutes mean is drawn. The raw data are the untreated measuring values and the processed data are the calculated values, or for example in case of the solar irradiance readings, values disposed of obvious outliers, negative values, invalid data points or gross measurement errors, which have a disproportionate effect on statistical completeness or analysis.

Figure 3. The indoor and outdoor measuring stations.

Apart from the direct readings from the sensor channels, other variables and composed indices are calculated to be displayed and recorded, like, for instances:

- Operative room temperature (OT)
- Running Mean Outdoor Temperature (RMOT)
- Wind Chill (WC)
- Thermal Comfort – Perceived Mean Vote (TC-PMV)
- Thermal Comfort – Perceived Percentage Dissatisfied (TC-PPD)
- Vertical Air Temperature Gradient – Percentage Dissatisfied (VATG-PD)
- Room Air Temperature Fluctuation (ATF)
- Indoor Dew Point (IDP)
- Outdoor Dew Point (ODP)
- Draught Rate – Perceived Percentage Dissatisfied (DR-PPD)
- Indoor Absolute Humidity (IAH)

Software Tools

Two software structures were developed, the first one dealing with the data handling, from acquisition till storage, and the second one with the data reduction, processing, analysis and visualization. The first tool is called Volkerak and includes four types of threads are being used for the data handling:

Data acquisition: This type of thread is responsible for reading messages from a sensor at regular intervals and publishing these messages in a dedicated data stream.

Message parsing: This thread subscribes to a single stream created by a data acquisition thread and parses a numerical value from the sensor message to a specified format.

Calculation: This thread can subscribe to multiple numerical data streams (after message parsing), perform calculations and publish the numerical result of these calculations into a new dedicated data stream.

Logging/storage: This type of thread collects data from numerical data streams of interest and stores these data, as it arrives, in a .txt file every 5 minutes.

It is installed both in the Work Place (WP) unit and in the Building Manager (BM) unit. It has been written in C/C++ and is modular in set-up (for future addition or change of sensors for example). An additional utility program takes care of the data streaming (multiple 5 minutes text packages) from the mobile unit to the base station by means of radio modems.

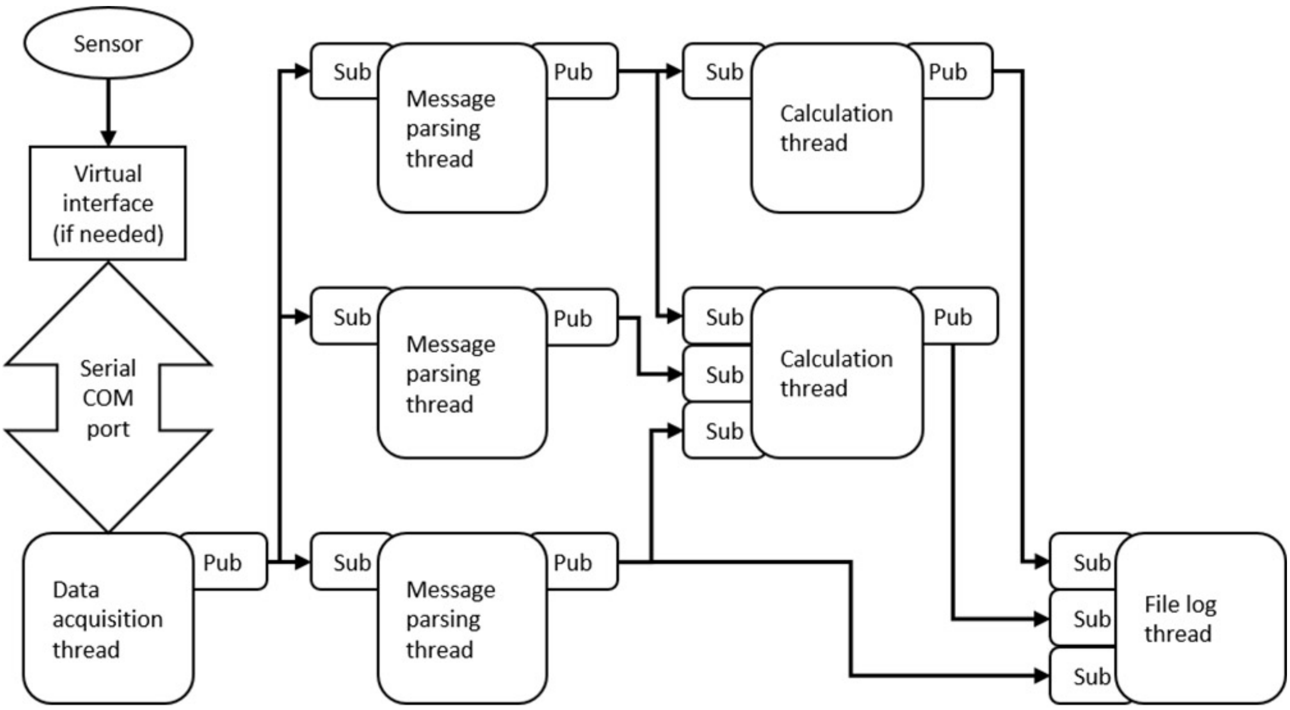

Figure 4. Data handling Volkerak software structure.

The second tool is called Discoverer and it is a multiple windows data presentation and analysis tool written in the programming language Labview. It accesses the Data Container, the folder with the daily data files created by Volkerak. Three different files (indoor probes, outdoor probes and infrared sensors) are saved each day, containing measured values recorded each 5 minute.

The windows of the Discoverer software tool are following described:

01 Dashboard: Window with the last measured values. It is refreshed each 5 minute and displays the time tag and the values of indoor (WP) and outdoor (BM) probes, together with some of the calculated indices (e.g. RMOT, WindChill, PMV, PPD, etc.).

02 Data Streamer: Window where the values of all the indoor and outdoor probes are displayed for the date selected by the user. It is possible to scroll along the time of the day, independently for indoor and outdoor probes.

03 WP Graphs: Window where two different graphs are depicted, based upon the selection of the user among the list of the indoor probes. The user selects the date of the first day and the number of days to be graphed. I tis possible to generate an output file with the data of the two displayed graphs.

04 BM Graphs: It is similar to the previous window, but it deals with outdoor sensors.

05 IR Sensors: Window where the values measured by the infrared temperature measurement probes are displayed. Each probe has an array with 16 measuring points (4 x 4). Besides the arrays with the numerical values of floor, ceiling and façade probes, color maps (interpolated and not interpolated) are also presented. It is possible to scroll along the selected day.

06 Adaptive Model: Window where the Building Adaptive Model graph is displayed, following the model defined in Dutch ISSO 74. The daily indoor operative temperature, during the user defined occupancy period is displayed as a function of the running mean outdoor temperature. The user may select the displayed period, indicating the first day and the total number of days.

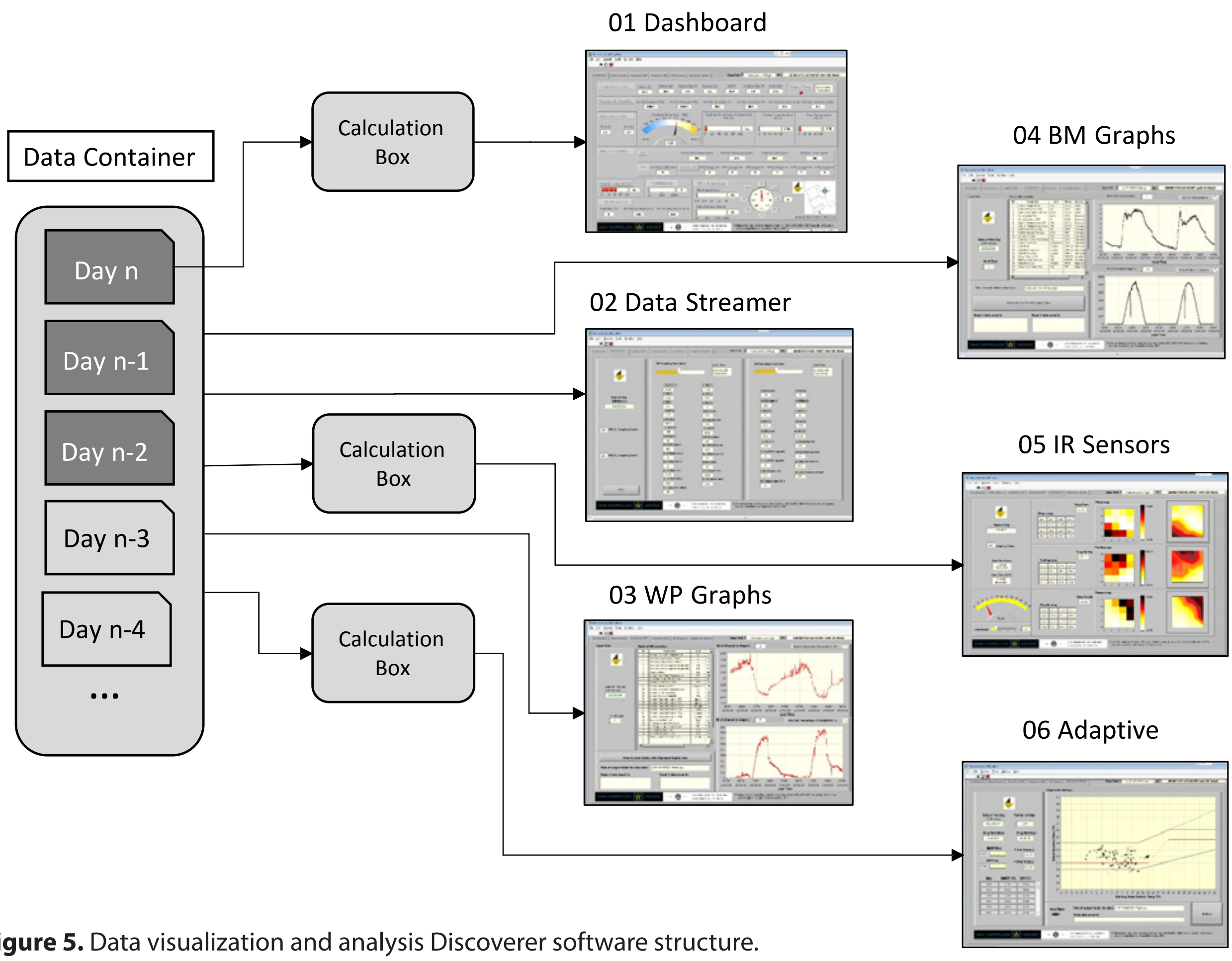

Figure 5. Data visualization and analysis Discoverer software structure.

Results

The results of a consult of the building database, obtained through remote access to the Discoverer software tool installed in the BM computer, are following presented. The access was done in the 11th of March 2018 and the first captured screen refers to the Dashboard window (**Figure 6**).

The graphical interface is divided into 8 different zones, with the first four rows, from top to bottom, being used for Temperatures, Pressures and Humidities, Thermal Comfort and Indoor Quality data, respectively. In the left down corner, three zones are dedicated to Sound, Light and Air Movement values, while the down right corner is used to display outdoor Wind and Sun data. The display is updated each 5 minute i.e. at the same rate used to register the data.

The captured screen of the Graphics WP window, showing the time evolutions of the indoor operative and the thermal comfort index PPD, for the days 22nd and 23rd of February 2018, is presented in the **Figure 7**. The user may select, for graph 1 and graph2, any one of the 25 parameters included in the Table of WP variables. In the showed case, it is patent both the very good thermal environmental conditions of the building (PPD has not exceeded 6%, meaning a class A indoor enclosure) and the excellent resolution of the measuring and evaluation system.

A screen of the Discoverer BM window, captured for the same two days of February 2018, and showing the time evolutions of the outdoor air temperature and the solar radiance is displayed in the **Figure 8**. The outdoor temperature was oscillating between –4°C and 5°C, in an interval that may be considered normal for the season. The two days were sunny with the solar radiance reaching a maximum value of 540 W/m². It is noticeable in the two consecutive days, a perturbation in the solar radiance graph, a little bit before noon due to a shadowing episode of the probe, with a duration of about 20 minutes.

The window named IR Sensors, for the 29th of September 2017, is presented in the **Figure 9**. The floor, ceiling and façade surface temperatures are presented. In each case, values of 16 cells arrays of the three infrared probes are displayed, as well as the respective means, maxima and minima and the color maps in non-interpolated and interpolated versions. The user may scroll along the day, checking the data in 5 minutes' intervals.

A comparison of the building performance in the last Winter season (90 days starting in the 21st of December 2018) and in the last year Summer season (90 days counted from 21st of June 2017), using the Dutch standard ISSO 74 representation for the thermal comfort adaptive model, is presented in **Figure 10**.

The daily indoor operative temperature average, during the user defined occupancy period is displayed as a function of the running mean outdoor temperature, which is a weighted average of previous seven days mean outdoor air temperatures. The weighting factor has a maximum for the day before the one considered in the calculation and decreases as the days become more distant.

The band between the gray lines corresponds to the acceptance zone of the indoor thermal environment (80% satisfaction) and the red line is the optimal condition for ISSO 74 Dutch standard. The first flat section, from left to right, corresponds to the operative temperature set point in the heating season, the second sloped section to the intermediate season conditions and the third section, on the right side, to the cooling season set point.

It is observed that the building was practically always in the zone of comfort, occurring only three days outside this zone, but are points relative to days of weekend in which the building was not occupied. It is also noticeable that the set point chosen for the summer season was 23°C instead of the 24.5°C indicated in the standard.

A possible long-term key performance indicator for the indoor thermal environment is the average of the absolute value of the distance between the actual mean operative temperature of a day and the defined season's operative temperature set point. In the Winter season the value for this descriptor has been 1.11°C, while in the Summer season it was 1.23°C.

The HVAC contractor's control engineer, who's task it is to set and keep the IEQ performances as close to the performance objectives as possible without an unacceptable increase of occupant's complaints and to demonstrate during the Soft Landings period that the contractual obligations are met, is working together with the building manager to skim possible overheating or overcooling and optimize the operation of the systems and instruct the occupants regarding the settings of their room sensor (influence on room level); improvements are made where draught, noise issues etc. arise.

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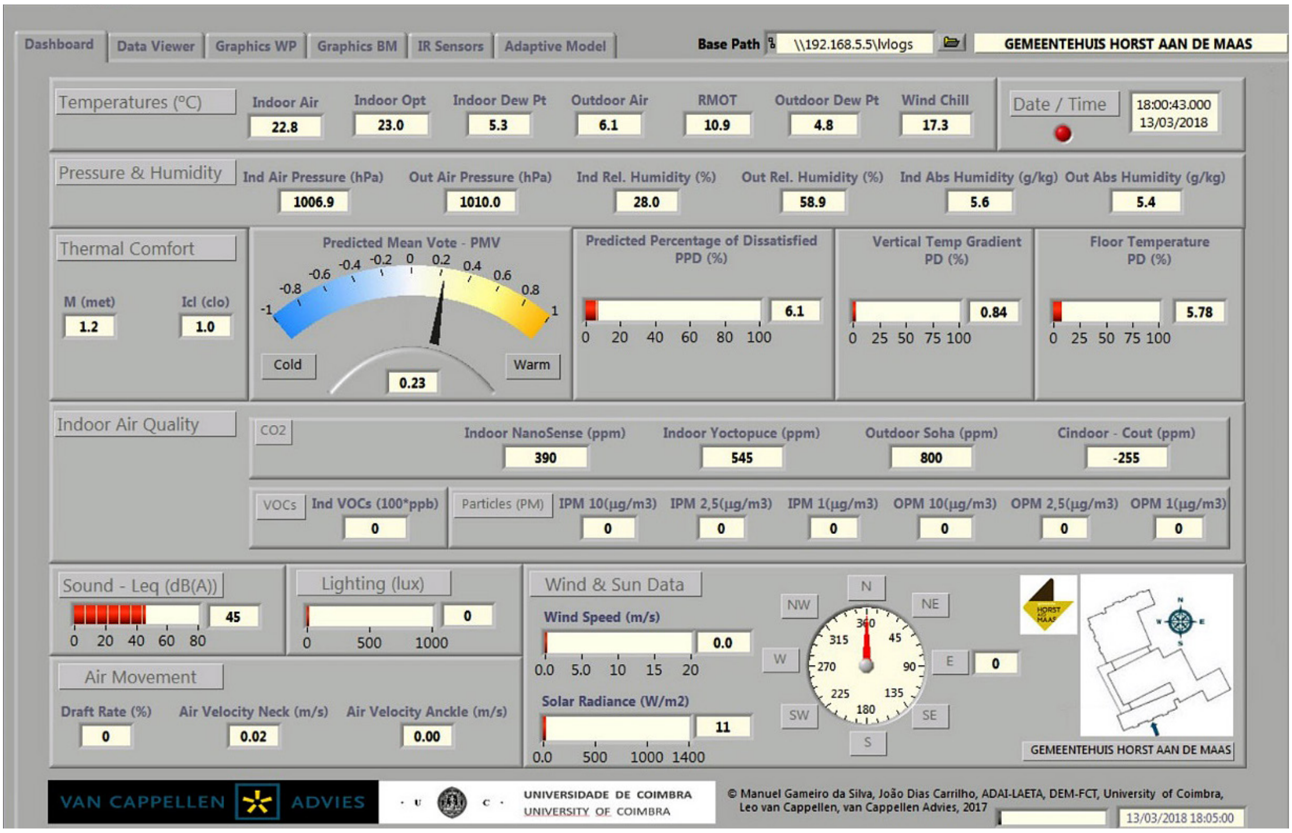


Figure 6. The Dashboard window of the Discoverer software tool.

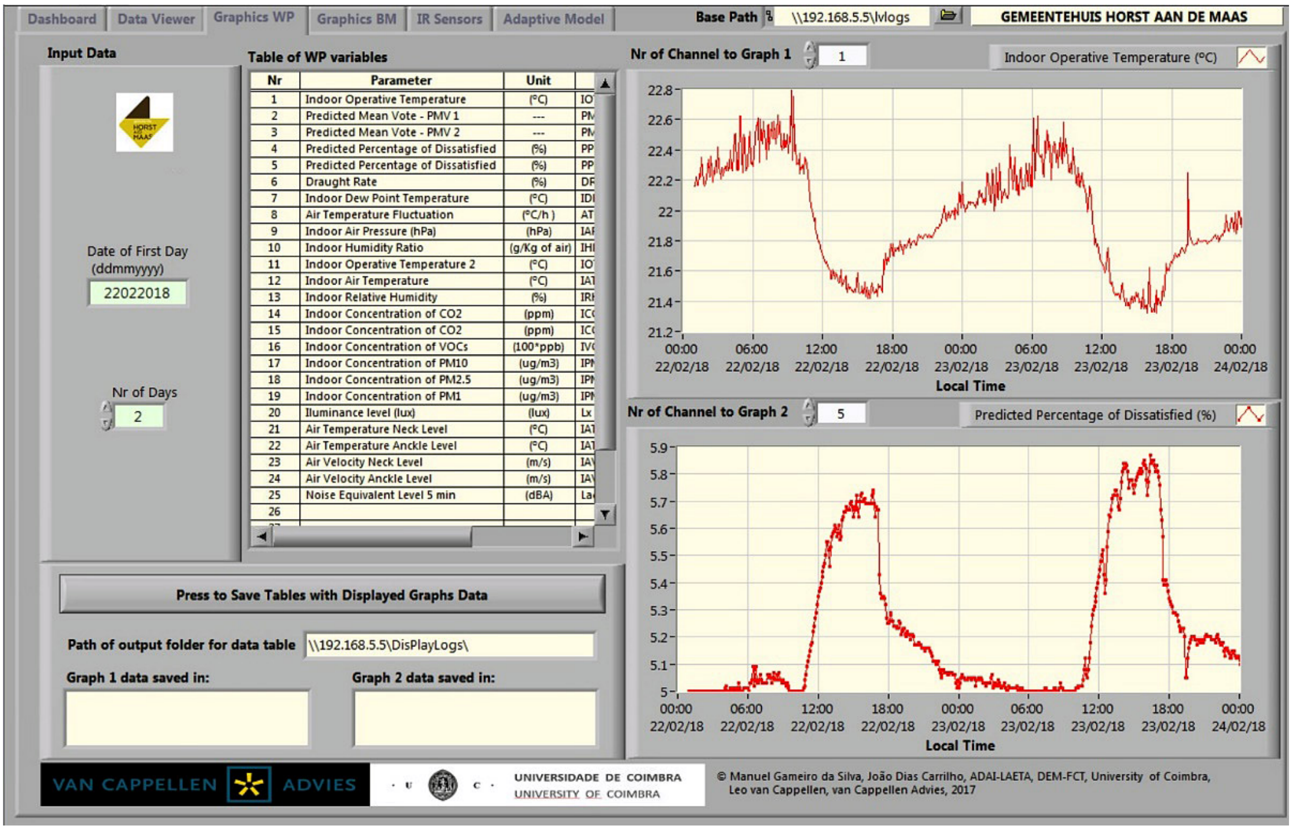


Figure 7. The Graphics WP (indoor work place) window of the Discoverer software tool.

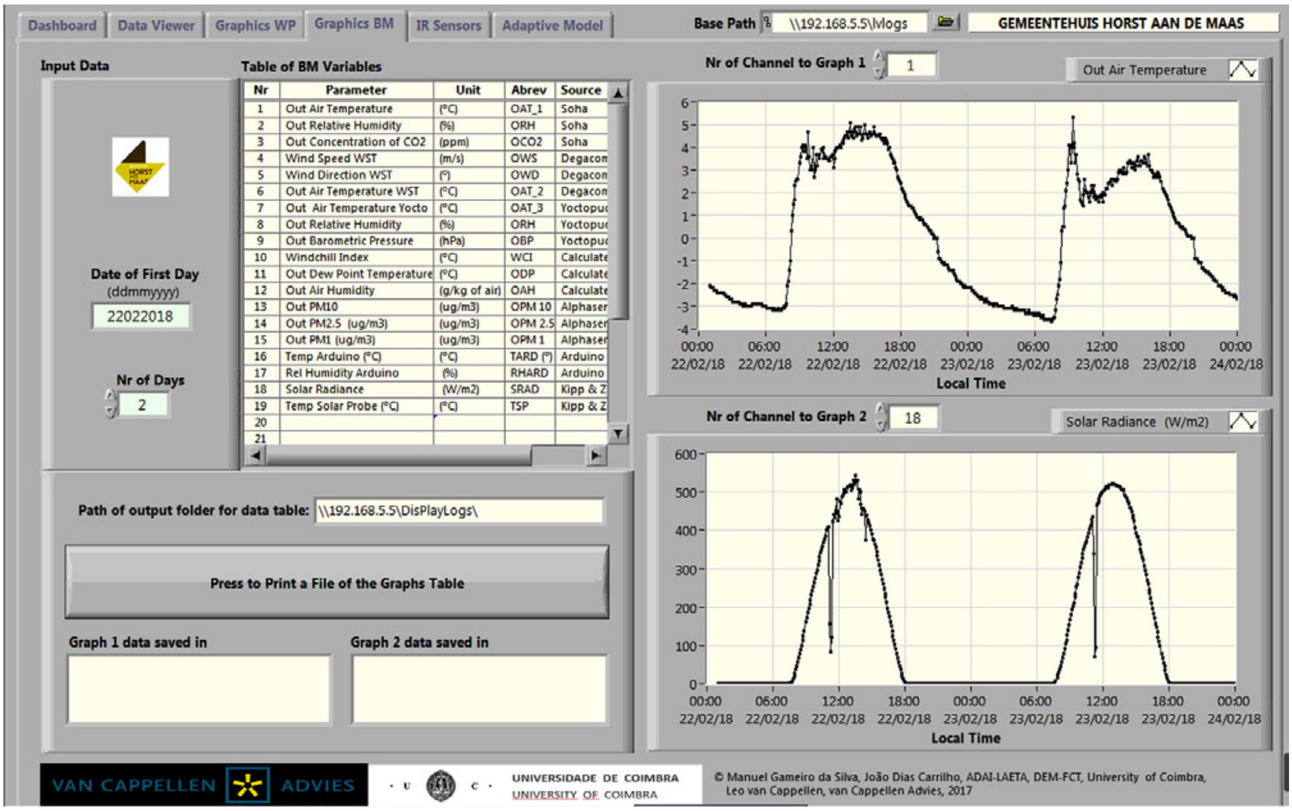


Figure 8. The Graphics BM window of the Discoverer software tool (outdoor station unit).

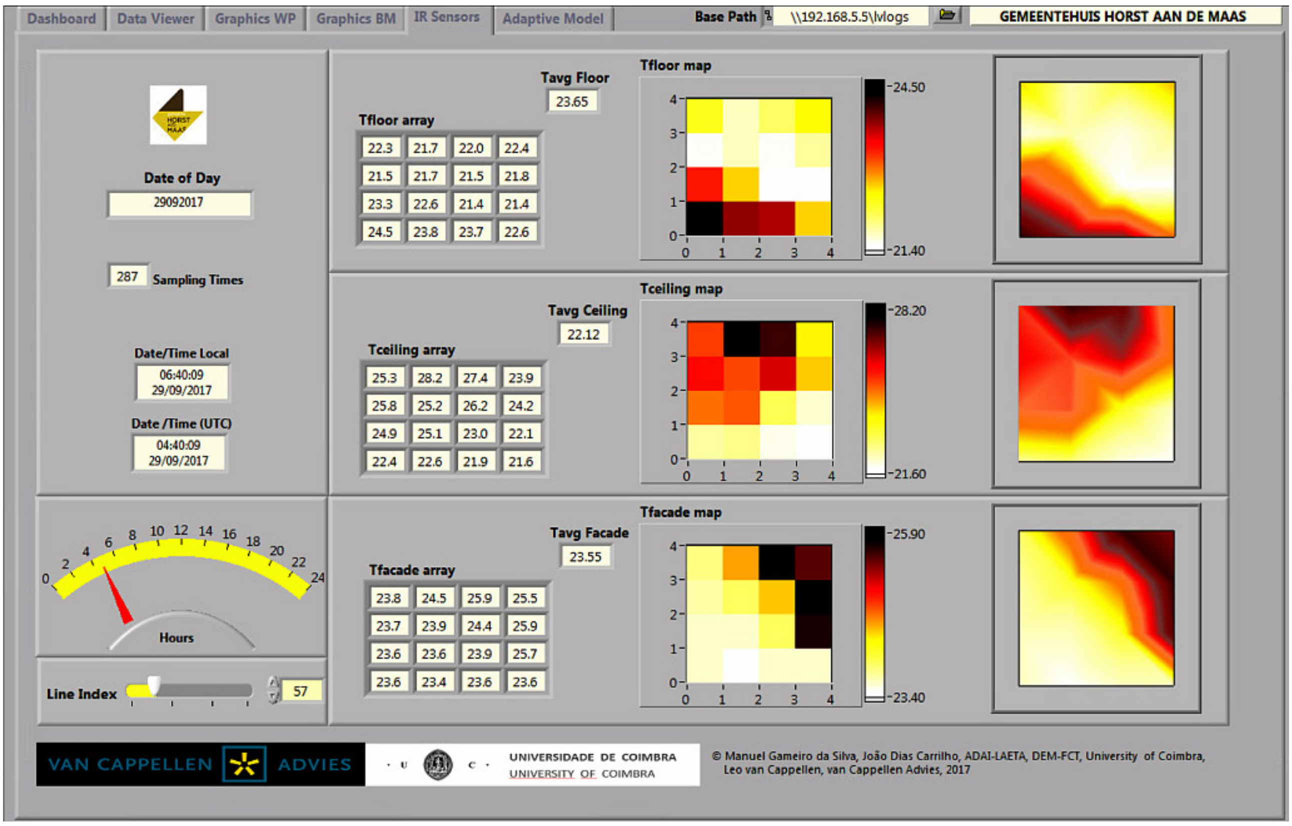
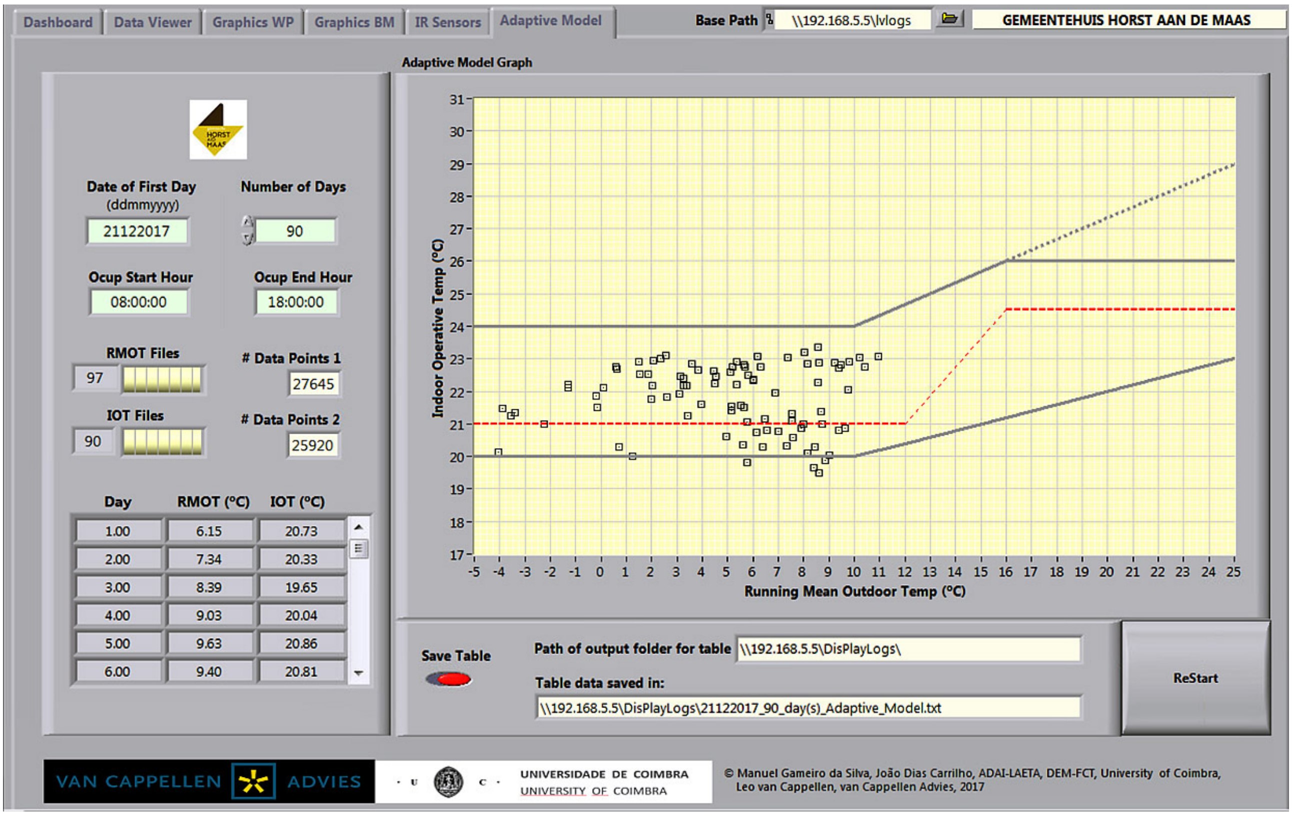


Figure 9. The Infrared Probes window of the Discoverer software tool.



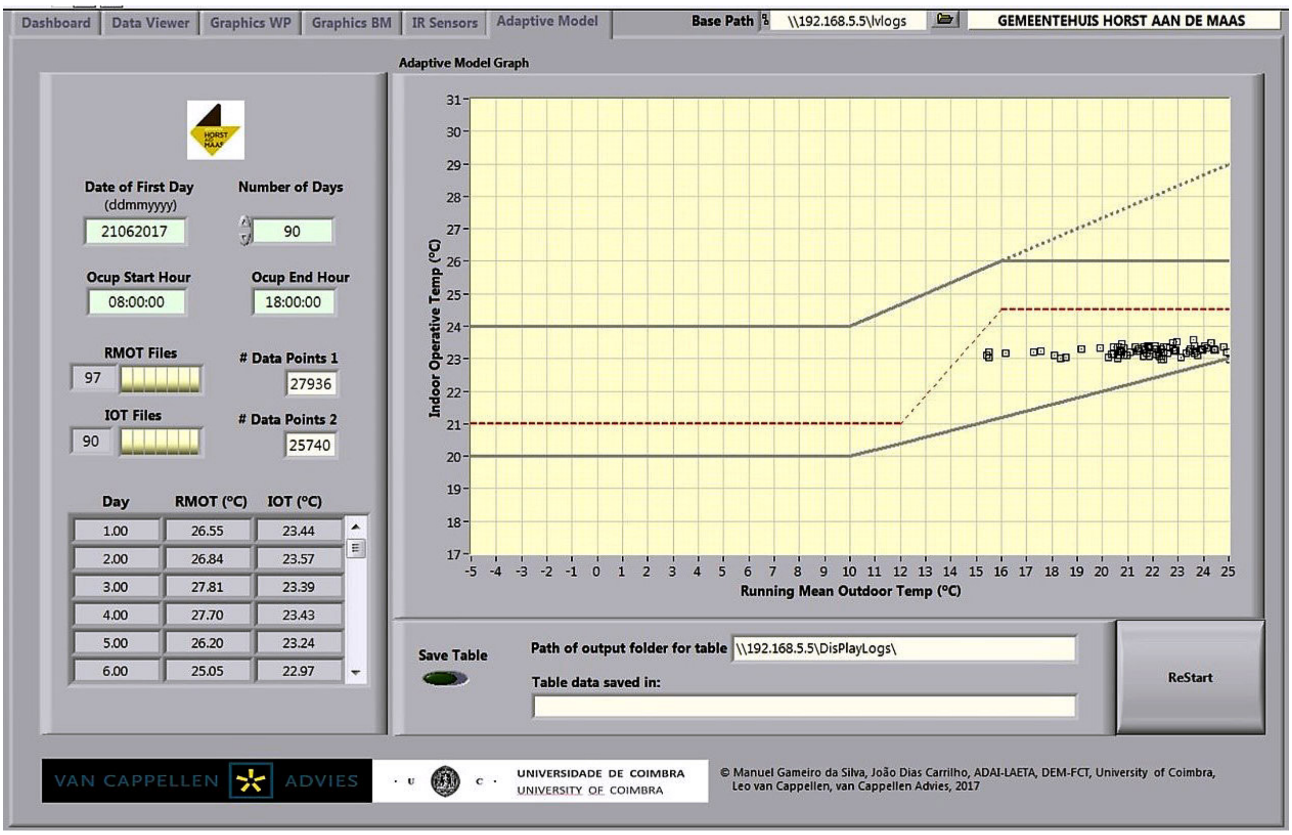


Figure 10. The Adaptive Model window of the Discoverer software tool. Comparison of Winter and Summer seasons.

The control engineer, who had only the BM database available, has been made familiar with the use of the monitoring system and according to his words: "a world of insights has gone open".

A bycatch of the monitoring system's operation is the discovery of hidden energy consumption, due to for instance overventilation, ventilating during off-hours, floor heating and air cooling on in a room at the same time, and not in the least malfunctioning or wrong settings of the control systems.

Conclusions

The concept initially defined for the IEQ monitoring system proved to be adequate and has been successfully implemented. The system allows to follow the building indoor conditions in terms of the various discomfort stressors and a relevant database is being created since more than two years ago.

The monitoring system is recognized by the building management team as an important tool in their effort to provide building well-being conditions to building occupants. New long-term key performance indicators regarding the different indoor ambiance areas (thermal, indoor air quality, noise and lighting) will be explored in the next phase of the project. ■

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