Healthy Buildings 2017 Europe
July 2-5, 2017, Lublin, Poland

Paper ID 0291 ISBN: 978-83-7947-232-1

Healthy buildings: IEQ objectivation by real time monitoring.

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KEYWORDS
Indoor Environmental Quality, Thermal Comfort, Indoor Air Quality, Distributed Environmental Monitoring, System Integration, IEQ performance objectivation, new building procurement, IEQ expectations, management of expectations, IEQ-gap, occupants, wellbeing, IEQ Post Occupancy Evaluations, IEQ complaint management, IE completion, IE specialist, Building Management System, Soft landings, Big Building Data.

SUMMARY
The need for objectivation of the indoor environmental quality (IEQ) increases since building project procurement practices, like Design and Build etc, lay the entire burden of responsibilities for the specification and realisation of IE performances with competing market parties. Post completion complaint management only, with or without the help of structured evaluation tools, like questionnaires etcetera, is not enough to establish whether or not the contractual obligations have been fulfilled.
This paper describes an easy to use professional *IEQ measuring/monitoring/logging system,* putting together indoor and outdoor measurements and presenting on a dashboard real time results at a glance. Although high quality sensors and auxiliary equipment are used, the sole purpose of the concept is to produce a sufficiently accurate level of measurement that can be held against the expected performances, in order to assess instantaneous values and value trends during the day. The sensing scope of the system allows also for a more integrated examination of the indoor environment quality than any building service can offer.
In a co-paper[4[a light is shed on the market mechanisms influencing the IE performances and the need for objectivation.

1 INTRODUCTION

The recent renovation of a substantial part of the 7,600 m^2 town hall of Dutch Municipality Horst aan de Maas, 42,000 inhabitants, has found its basis in completely outdated building services, in particular in dated HVAC systems and poor IEQ performance. Further the 10 year old, better

performing HVAC systems in a new build extension from 2004 were to be subjected to a thorough check-up, reset and recommissioning.
During the IE performance specification process[2[it becomes clear that not only wishes this professional employer to have a solid contractual basis for the new IEQ ambitions, extensive autonomy over inhouse IEQ assessment facilities too is required. It was decided that the Municipality should buy IEQ measurement equipment and let it not be part of the contracted scope of installation renovation work.
The development of what at a later stage is called by its nickname “The EMU”, after the curious walking bird, turns out to be a step-by-step process. Starting with a pc-based thermal comfort sensor set, consisting of two draught sensors (air velocity and air temperature at neck and ankle level), a black globe sensor (radiant temperature) and a relative humidity sensor connected by USB to a laptop on which Thermal-Comfort-software is installed. A simple on site measurement configuration, with data handling by an internal or external expert.
But the ambitions are considerably bigger and have resulted in today’s configuration: a real time IEQ measuring/monitoring and data logging system for the objectivation of physical working conditions in offices; also suitable for schools and other non-residential buildings though.
The general objective of this set-up is to provide for sufficiently accurate indicative measurements for field application and assessment purposes. The system’s output is explicitly of a ‘first impression’ investigative level. Lab quality is not an ambition.
It should offer insights in the dynamics of all the measured parameters, not only during the normal working hours, but also after, for example to see the effect of installation shut off and start-up procedures during the night and weekend periods. Another interesting outcome is to observe the degradation of building system performances during years. The ambient sound pressure level due to installations during the evening/night, can be taken as an example for assessing whether or not is complied with the contractual performances.
In case of (legal) disputes due to substantial anomalies from expected performances, uncovered by the system, a higher level of measurement accuracy might be required, along with professional expertise, guidance and advice.

The initial main development objectives for the project are:

a. Develop a mobile indoor sensor unit for work place measurements. The unit must be easy to handle by non-expert facility personnel. The unit must be plug and play, without the personnel having to take any special action to get it going after relocation.
   Data loss due to relocation of the mobile unit is not acceptable.
b. Develop an outdoor sensor unit, in order to be able to relate the indoor environment to the outdoor environment.
c. Both units must produce real time streaming data.
d. Develop a base unit that collects, processes, computes the relevant descriptors and indices and stores the streaming data in the form of data files per day.
e. Develop a presentation/dashboard system that visualizes the presented real time values every 5 minutes and facilitates professional analysis and report making.
f. Measured data should never be lost.
g. Data communication, either cabled or wireless, should be completely independent from any corporate infrastructure.
h. Hardware, sensors in particular, must be commercially available on the market. No own development.
i. Software is to be specially developed into a modular, adaptable concept, which makes future changes easily possible. Widely used software platforms are to be preferred.

The ambitions of this project are restricted to monitoring IE data, which, of course, can be professionally assessed and interpreted and reported about by an IE specialist, but which explicitly in an educational sense, can be real time observed by non-professionals like facility personnel. The long-term benefits of that can be subject of further study.

The key motivation of setting up this project is the awareness that, as a rule, at building level one knows hardly anything in particular about the IE during the use of the building. Knowledge and perception in general, of all stakeholders involved, are subjective. The lack of objectivation feeds dissatisfaction more than probably needed. Clarity and understanding could do much good, also in terms of better focussed improvement measures in case of imperfections in the marriage of building envelope, building services (HVAC, lighting) and the occupants and their equipment.

2 MATERIALS/METHODS

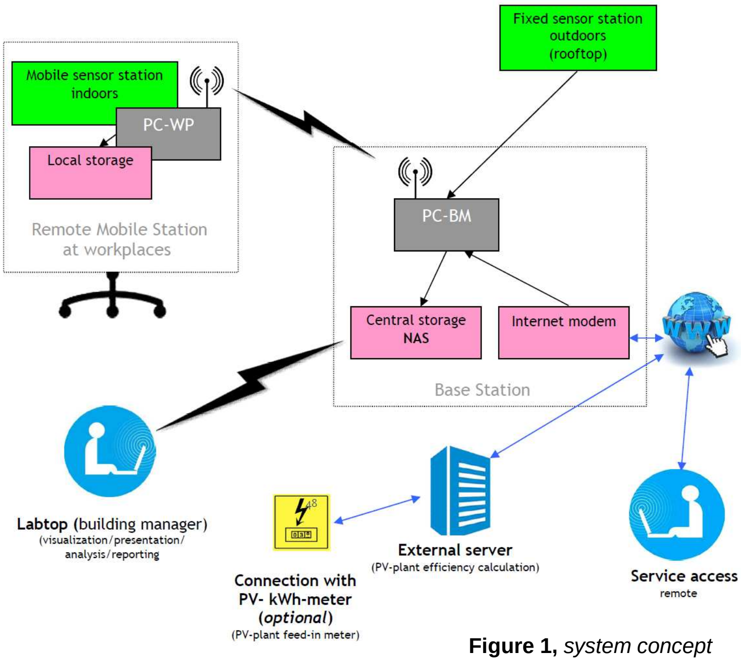


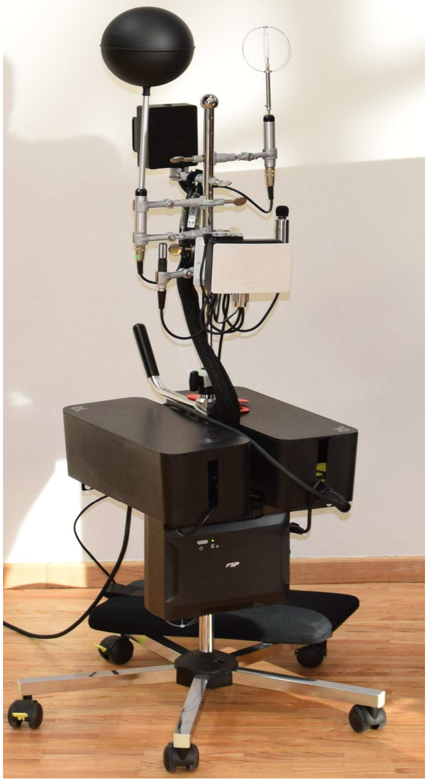
Figure 1, *system concept*

HARDWARE

The developed IEQ-objectivation concept (figure 1) consists of four major hardware parts:

a. Mobile sensor station (figure 2)
b. Fixed outdoor sensor station (figure 3)
c. Base station (figure 4)
d. Building manager's station

Figure 2, *indoor sensor station (mobile)*



The *mobile sensor station* (WP(workplace)-unit) (figure 2) has the following sensors on board:
1. mean radiant temperature (black globe), 2. air velocity/temperature/barometric pressure, neck position; 3. air velocity/temperature, ankle position, 4. surface temperatures floor/ceiling/wall-window, 5. relative humidity, 6. sound pressure level (A weighted), 7. illumination level, 8. CO_2, 9. VOC's, 10. fine particle matter PM10, PM 2,5, PM 1.0.

The mobile sensor station is further equipped with sensor interfaces, RS 485 sensor USB isolators, a powered hub for USB sensor connections, a mini-pc, a SSD flash storage, a common power supply 230 V and DC converters, an uninterruptible power supply UPS, a powerline adapter for data communications at base station docking service situations and a radio modem (transmitter) for wireless data streaming to the base station. The sensors and other equipment are mounted on a dolly, being a modified IV-pole. The mobile station can be put freely at each workplace; only the 230 V power has to be plugged in.

The *fixed outdoor sensor station* has the following sensors on board: 10. air temperature, l1. relative humidity, 12. barometric pressure, 13. wind velocity/direction, 14. solar irradiance, 15. CO_2, 16. fine particle matter PM10, PM 2,5, PM 1.0.
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 ^{o}C to 40 ^{o}C; high humidity levels).
The outdoor station is further equipped with USB over Ethernet LAN data line extenders (powered local units), a common power supply 24 V and DC converters.

Figure 3, *outdoor sensor station*

The outdoor sensor station is connected by cat data cables (non-corporate cable infrastructure) with the base station; cabling has surge protection.
The *base station* (BM(BuildingManager)-unit) is an instrumentation cabinet, located in the basement of the building, equipped with a mini-pc, a monitor, a keyboard, a camera, speakers, a router, a network attached storage NAS, a common power supply 230 V and converters to 24 and 12 VDC, a powerline adapter for data communications from the mobile station at base station docking service situations, USB over Ethernet LAN dataline extenders (non-powered local units), surge protection in the data cables and a radio modem (receiver) for wireless data streaming from the mobile sensor station.

Figure 4, *base station*

The *building manager's station* is a laptop on which presentation/dashboard software runs and with which analyses 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 min 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.
What are the calculated output data, apart from the direct readings from the sensor channels, shown on the dashboard?

1. Operative room temperature (OT)
2. Running Mean Outdoor Temperature (RMOT)
3. Operative Outdoor Temperature (OOT) (future)
4. Wind Chill (WC)
5. Comfort range with upper and lower limit lines of adaptive model (Ashrea standard 55; modified to Dutch conditions in ISSO 74)
6. Thermal Comfort - Perceived Mean Vote (TC-PMV)
7. Thermal Comfort - Perceived Percentage Dissatisfied (TC-PPD)
8. Air Temperature Difference Neck/ankles (ATD)
9. Vertical Air Temperature Gradient - Percentage Dissatisfied (VATG-PD)
10. Room Air Temperature Fluctuation (ATF)
11. Radiant asymmetry warm/cool ceiling (RAC)
12. Radiant asymmetry warm/cool floor (RAF)
13. Radiant asymmetry warm/cool wall/window (RAW)
14. Indoor Dew Point (IDP)

15. Outdoor Dew Point (ODP)
16. Draught Rate - Perceived Percentage Dissatisfied (DR-PPD)
17. Indoor Absolute Humidity (IAH)
18. Outdoor Absolute Humidity (OAH)
19. Absolute Humidity Difference (AHD)
20. Mean Air Velocity (MAV)
21. Turbulence Intensity (TI)
22. CO_2-level Difference Indoor/Outdoor (CO2-D)
23. Illuminance level (IL)
24. 5 min A-weighted noise exposure level (NEL)
25. Daily 8h A-weighted noise exposure level (NEL(8h))
26. Solar irradiance (validated) daily total (SI(24h))

SOFTWARE

Special software is developed on two levels:

a. data handling (from acquisition to storage)
b. data presentation/visualisation

Four types of threads are being used for the data handling program:

* *Data acquisition (figure 5)*
  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.

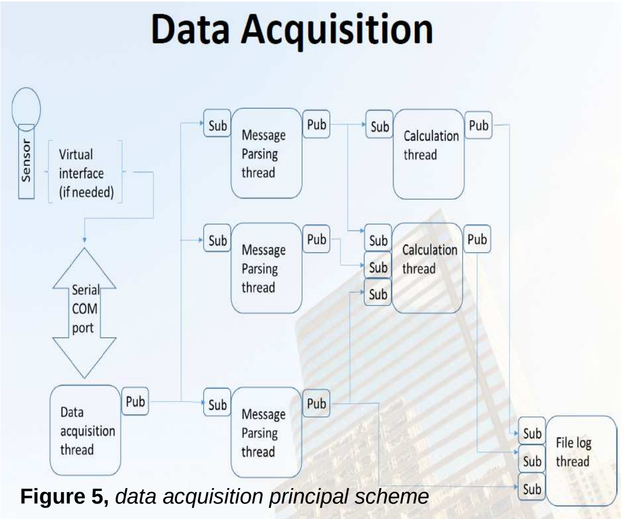


Figure 5, *data acquisition principal scheme*

There are two separate programs, called Volkerak, one for the Work Place (WP)unit and one for the Building Manager (BM)Unit.

The programs are written in C/C++ and are 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 min. text packages) from the mobile unit to the base station by means of radio modems. Raw and processed data are stored locally (on the flash drive in de mobile WP unit), and on the big redundant storage (NAS) in the base station.

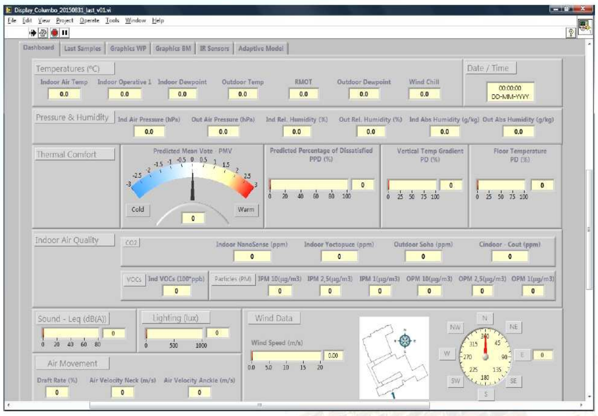


Figure 6, *dashboard on Building Manager's laptop*

The second program is a Labview application for real time presentation and visualization on the Building Manager's laptop (figures 6, 7 and 8).

The available data are extracted from the storage, and where planned, are subject to further calculations and are presented on a dashboard, that refreshes itself every 5 minutes.

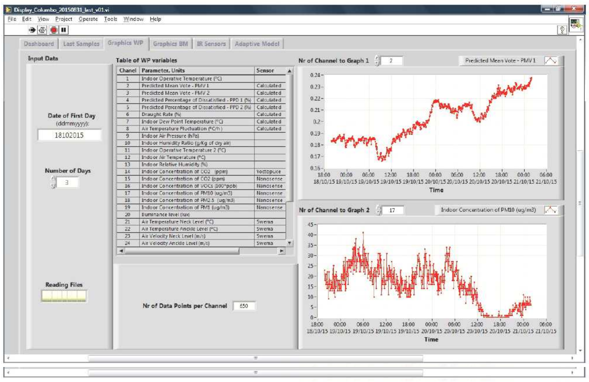


Figure 7, *data viewer indoor on Building Manager's laptop*

Figure 8, *data viewer IR sensors on Building Manager's laptop*

Apart from a troublesome sensor now and again during in the development stage, the data stream (partly wireless) flawlessly, the calculations are made properly and the entire performance fulfills the expectations. Yet several optimizations can be made, such as the application of cheaper hardware components, like mini-pc's, wireless communication modems, some sensors, interfaces etc.
Further ambitions, like automated indoor positioning of the mobiles unit, extended application of indoor and outdoor air quality sensors, application of outdoor weather data into information for IE experts (degree days, Mollier diagram positioning, load duration curve generation) and the application of artificial intelligence techniques for further analysis of the big building data, are on the wish list.

3 CONCLUSIONS

The newly developed real time measuring/monitoring/logging concept as described serves its purpose and reveals the IE reality. This type of objectivation either confirms that the condition at a measured workplace is conform the intended performances or shows differences. It is a tool for the IE expert to evaluate a given situation and to make substantiated reports. For the building manager, not being an expert, the IE is brought to life for him/her and after some time the information from the dashboard begins to tell an understandable story.
Undeniably however, the (subjective[3]) perception of the building's occupants remains a matter of great prominence and attention. Objectifying alone will not make the wellbeing[1][2] of occupants better, but the insights from measurement data assist the IE expert and the facility manager to better deal with the post completion and after care phases[4] of a new building and with the management of complaints when the building is in use.

4 REFERENCES

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