Monitoring Guidelines for Energy Efficient Buildings

1. *Introduction*

This document aims to provide methodology for planning, managing and reporting building monitoring campaign.
It is well known that modern energy efficient buildings are usually provided of detailed Building Energy Management System. The BEMS controls building environment, mechanical and electrical systems, etc.. This system is critical for the optimized energy control of the building and the plants. An efficient control of building environment and HVAC plant is necessary condition for achieving energy efficiency of the building and it is the result of a congruent design process of both hardware and software systems. Because monitoring plant is embedded in BEMS, these systems allow, in many cases, the possibility of data recording for days or weeks, then they can accomplish not only the control task, but long term monitoring task as well. For its own nature, BEMS should be able to provide a detailed monitoring network: indoor conditions of almost all rooms of these kind of buildings are continuously monitored (Room temperature), all main plants functions (heating, cooling, ventilation, lighting) are controlled and their status recorded.
On the other hand, in many cases, buildings are not provided of BEMS: monitoring their performances, in terms of energy performances and of thermal comfort, for commissioning, energy performance certificate or for demonstration purposes, need to develop a specific monitoring plan.
The aim of this document is to provide a guideline of monitoring these kind of buildings and or integrate what not previously foreseen and monitored by an existing BEMS.
The monitoring campaign on a new, or on a refurbished, building is usually strictly connected with the *Commissioning*, *Energy Performance Certification* or *Demonstration* procedures. The aim of monitoring is then, in different cases:

- to verify the well working of all systems and check energy consumptions/possible savings (Commissioning and Certification)
- verify the actual indoor climate in the building (Commissioning and Demonstration)
- make a comparison with the predicted use of energy and the predicted indoor climate (Commissioning and Demonstration).

2. *Road Map of monitoring campaign*

Planning and executing a monitoring campaign requires first of all the definition of the objectives. Road map of a monitoring campaign consists then of following steps.

2.1. Objectives definition

The main possible objectives of a monitoring campaign can be identified as follows, in order of increasing complexity and detail of monitoring plant.

Energy performance Certification
Commissioning procedures
Demonstration

2.2. Problems identification

For each possible objective, a list of possible problems/items-to-study can be defined

- o *Thermal indoor climate and IAQ*
- o *Energy performance*
- o *Plants efficiency*

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Once the objectives and problems are identified, the detailed monitoring procedures have to be defined. These procedures involve the following items:
- ü What and how to measure
- ü Where to take measurements
- ü Duration of campaign and when to take measurements
- ü Logging interval

In general, each building is characterised with its own particularities, then following lists and tables have to be considered as a comprehensive review of what should be taken into account if the case.

2.3. What to measure: Listing Parameters

2.3.1. Outdoor conditions

Outdoor conditions are important in order to check if the monitoring period is representative of climate conditions of the site: if not, the results of monitoring campaign (energy consumption for space heating) should be corrected to a reference year using the degree-day method. Parameters to be monitored in order to have a comprehensive outdoor conditions overview should be:
- ü Outdoor Temperature
- ü Outdoor Relative Humidity
- ü Wind speed and direction
- ü Global Solar Radiation
- ü Atmospheric pressure

For most of buildings monitoring of Temperature (hourly values) and Solar radiation (daily) can be sufficient. The other parameters can be advisable, sometime compulsory, in special cases (e.g. naturally ventilated buildings). For certification purposes it is probably sufficient to refer to meteorological data recorded at closest meteorological station, if available in proximity of the building.

2.3.2. Indoor conditions

Indoor conditions have to be characterized in order to demonstrate the overall well working of building. In general the following measurements could be complemented with a standard indoor climate questionnaire to find out how the users perceive the indoor climate, heating and ventilation system and how the building is used (e. g. occupancy profiles). Measurement have to take into account Indoor Environment Quality: Thermal comfort, IAQ and Visual comfort in one.

Thermal comfort
- ü Indoor air Temperatures
- ü Vertical Temperature difference
- ü Surface Temperatures
- ü Radiant Temperature asymmetry from windows or other cold vertical surfaces
- ü Operative Temperature within the occupied zone
- ü Relative Humidity
- ü Air Velocity within the occupied zone

IAQ
- ü Particles
- ü TVOC
- ü Carbondioxide
- ü Formaldehyde

Visual Comfort

- Illuminance

2.3.3. Plants

Plants are usually monitored by means of meters. A well monitored plants is often a well working plant. Metering *per se* does not save energy. It is the actions taken as a result of installing and monitoring meters that can achieve quantifiable energy savings. Meters that are selected and installed correctly provide the information for the monitoring and targeting process that is an essential part of energy management.
Metering systems play an important role in monitoring energy performance of buildings. Actions taken as a result of installing and monitoring meters often save 5-10% of the energy being metered. Sometimes they can save more. Metering helps building occupiers to understand where all the energy is going, and enables them to identify and monitor patterns of energy use.
Although the capital cost of individual meters has reduced in recent years, the cost of installing direct metering throughout a large building can still be significant. However, it is not always necessary to install large amounts of direct metering to establish end-use energy consumption: periodical readings on general meters can sometimes substitute a detailed metering plant. Very often meter can be substituted by a status (on/off) recorder: it is the case of constant flow pumps or constant velocity fans. In these cases recording operating time is sufficient and much less expensive than direct metering.

Energy and Water Consumption

- Thermal (space heating and hot water)
  - Temperature drop
  - Flows
  - Fuel
- Electricity
  - Electricity use for heating / cooling
  - Electricity use for ventilation
  - Electricity use for pumps etc
  - Electricity use for lighting
  - Operating time
    - Different fan speeds
    - Lights
    - Pumps
- Water
  - Flows

Renewable Contribution

  - Temperature drop
  - Flows
  - Electric Power

The applicability of parameter lists to different monitoring objectives is summarized in following tables.
X indicates that the parameters should be monitored
(X) indicates that parameters should be optionally monitored
X(a) indicates that parameters could be alternatively monitored

Monitoring item		External conditions: ü Climate definition											
Parameters		Ambient Temp	Relative humidity	Wind velocity	Wind direction	Global solar radiation	Atmospheric pressure						
Purpose of monitoring	Energy Performance Certification				(X)								
	Commissioning procedures	X	(X)	(X)	X	(X)							
	Demonstration	X	X	X	X	X	(X)						

Monitoring item		Interior conditions: ü Indoor environment quality											
Parameters		Thermal							IAQ				Visual
		Room Temp.	Vertical Temp. Difference	Surface Temp.	Radiant Temp. Asymmetry	Operative Temperature	Relative humidity	Local Air Velocity	Particle	TVOC	CO2	Formaldehyde	Illuminance
Purpose of monitoring	Energy Performance Certification	X											(X)
	Commissioning procedures	X	(X)	(X)	(X)	X	X	(X)			X		X
	Demonstration	X	(X)	(X)	(X)	X	X	X	(X)	(X)	X	(X)	X

Monitoring item		Plant: ü Energy efficiency / Water consumption ü Renewable contribution											
Parameters		Thermal			Electricity					W	Renewable		
		Temp. drop	Flows	Fuel	Elect. Meter for heating/cooling	Elect. Meter for ventilation	Elect. Meter for pumps	Elect. Meter for lighting	Operating time for fans and pumps	Water flows	Temp. drop	Flows	Electricity
Purpose of monitoring	Energy Performance Certification	(X)	(X)	X	X			X	(X)		X	X	X
	Commissioning procedures	X	X	X	X	X(a)		X	X(a)	X	X	X	X
	Demonstration	X	X	X	X	X(a)		X	X(a)	X	X	X	X

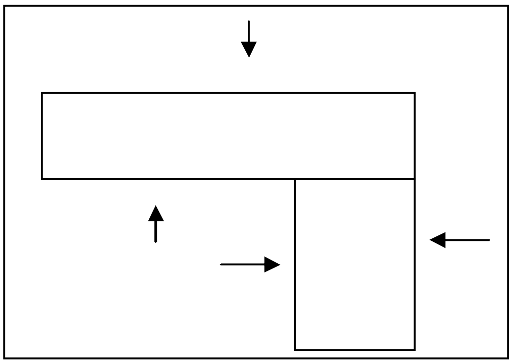
2.4. How to take measurements

Two main typologies of monitoring campaigns can be distinguished: *continuous* campaigns and *spot* campaigns. The first type requires, if not embedded in BEMS, specific monitoring plants, with capable dataloggers and an amount of sensors: can be quite expensive and it is usually justified only in case of demonstration buildings. The second one can be used with portable data loggers and periodical readings of meters (electricity, gas, water) at defined intervals (weekly, monthly) in case of certification and commissioning.

2.5. Where to take measurements

Each building has its own characteristics, then monitoring plan has to be specifically designed and tailored.

In general, thermal comfort measurements should be taken in at least **one room for each main building facade.**



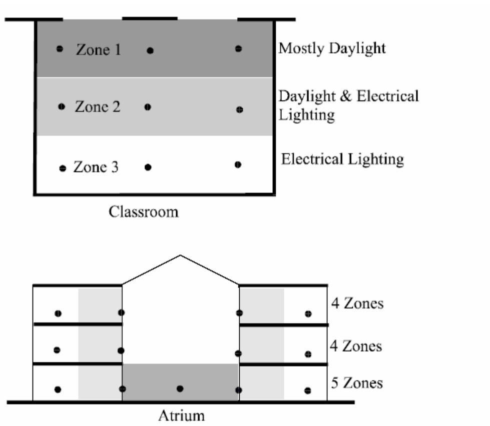
For building with **more than three floors** it should be important to take measurements at **different levels**.

Further data should be recorded in **atria and corridors** in order to give information on general indoor climate and on differences between rooms and passage environments.

Vertical temperatures difference can be recorded in rooms higher than 3,5 m, in order to make evident stratification phenomena.

Operative Temperature, and Radiant asymmetry as well, should be recorded at selected workplace, preferably where radiant asymmetry can be an issue (in windows proximity etc.).

For visual comfort, existing monitoring guideline (Daylighting Monitoring Protocols & Procedures for Buildings - Atif, M.R.; Love, J.A.; Littlefair, P.; IEA Task 21/Annex29) suggests to take measurements as in following picture



Daylighted zones of the selected space should be defined prior to the selection of the measurement points. These zones should be defined based on their distance from the window, (or atrium skylight), and based on the activity in the zone. Measurement points should represent typical illuminance in each daylighted zone. The number of daylighted zones and test points depend on the dimension of the space, and on the activity.
A private office with sidelit window should not have more than 2 test points, one for each daylighted zone, one of which has to represent a dark area. The number of daylighted zones in an open plan office should be at least equal to the number of workstations in the selected space. A minimum of one test point at the working plane level (75 cm above the floor) should represent each workstation. The test point can be at center of the zone or represent a critical location of the activity, e.g. desk. A large classroom, for instance, may require three zones, with three test points at each zone to represent illuminance at the front, middle, and on the back of the classroom. The test points on the sidewalls should be about 1 meter away from the walls, and measured at the working plane level (75 cm above the floor).
In an atrium space, each floor, including the atrium floor, should be considered as a separate zone. At least four test points are required in each adjacent space or floor, two on the east and two on the west. The atrium floor should include at least three test points (center, east, and west).

2.6. Monitoring duration and logging intervals

For demonstration purposes, long term monitoring programme (heating and cooling seasons; one year) should be planned accordingly to the climate of the building site, especially for all parameters included in the BEMS. However, even in presence of a building energy management system, acquisition of parameters not included in integrated system would be advisable, according to what stated in the above mentioned tables.
As already mentioned, continuous long term monitoring can be very expensive, if not yet foreseen in BEMS, as alternative it is possible to develop (or integrate what already foreseen in BEMS) a system in order to monitor selected parameters for one or two weeks during **significant periods**. These periods are:

- ‘Border periods’ of heating and cooling seasons (Start and end of heating period Start and end of cooling period)
- Midwinter
- Midsummer

Logging interval is an important parameter in monitoring campaign: detailed studies require shorter logging intervals. In general, as more innovative the building is, as more detailed the monitoring campaign should be.
The following table summarizes *minimum requirements* for appropriate monitoring duration and logging intervals for different monitoring purposes

Purpose	Location	Type	Duration	Readings intervals	Logging Intervals
Certification	external	refer to closest meteo station	one year		
	internal	Spot	one year	Monthly	
	plants	Meters readings	one year	Monthly	
Commissioning	external	refer to closest meteo station	one year		
	internal	Continuous	one year		hourly
	plants	Meters readings	one year	Monthly	
Demonstration	external	Continuous	one year		sub hourly
	internal	Continuous	one year		sub hourly
	plants	Continuous	one year		sub hourly

3. *Data Analysis*

The data gathered can reveal useful trends between, say, day/night, summer/winter, weekday/weekend. It can allow operators to:

- ü compare actual consumption with targets
- ü spot things going wrong before it is too late
- ü maintain one year moving averages
- ü Cumulative Sum plots to see which way trends are going.

3.1. Local Weather

In order to understand if monitored period climate values are on line with average local climate, all value will have to be compared to reference data. Typical analysis of weather data are:

Temperature: Monthly min, mean, max (comparison to reference data)
Degree days: comparison of measured data to reference data
Solar Radiation: comparison of monthly measured data to reference data
Wind diagram (frequency and maximum velocity per direction)

3.2. Energy consumption

3.2.1. Energy Demand: Electricity

	[kWh/m²a]	Total annual (kWh)
Total electricity		E1
Electricity consumed by ventilation		E2
Electricity consumed by heating		E3
Electricity consumed by cooling		E4
Electricity consumed by DHW		E5
Electricity of kitchen or special high-energy units		E6
Electricity consumed for lighting		E7
Primary Energy (Total electricity)		PE_E

3.2.2. Energy Demand: Thermal

	[kWh/m²a]	Total annual (kWh)
Total incoming heating energy (district heating/solar/gas/oil), measured from the main supply line (temperature drop/flow vs. oil/gas consumption*Heating value)		T1
Heating energy consumed by ventilation		T2
DHW		T3
Primary Energy (Total thermal)		PE_T

3.2.3. Contribution from Renewable

	Total annual	Renewable fraction
Solar Thermal	R1	R1/T3 (R1/T1)
PV	R2	(R2+R3)/E1
Wind power	R3	

3.2.4. Water consumption

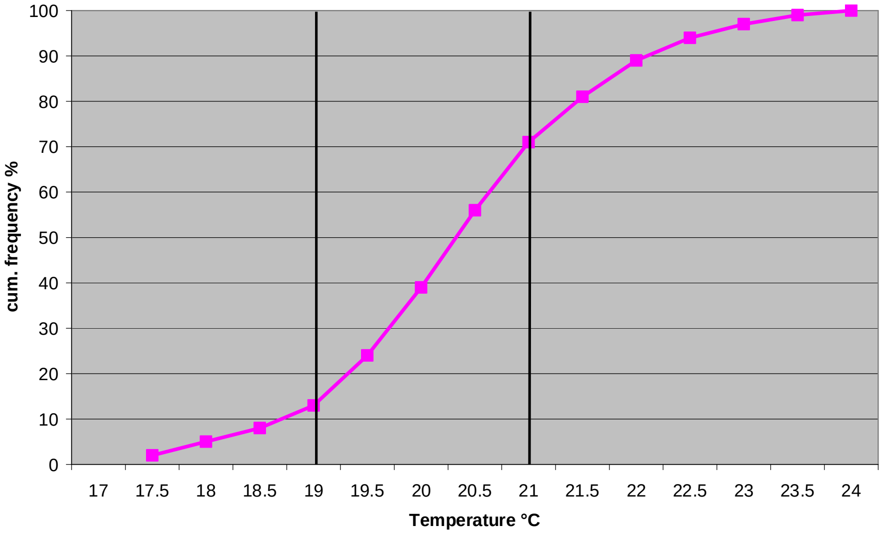
		Total for the whole building
Water	… m^3/m^2a	… m^3/a

3.2.5. Primary energy calculation

		Total for the whole building
Space heating	… $kWh/m^2 a$	… kWh/a
DHW	… $kWh/m^2 a$	… kWh/a
Electricity	… $kWh/m^2 a$	… kWh/a

3.3. Thermal comfort

A convenient way of representation of thermal comfort is cumulative frequency curves of calculated PMV (PPD) during working hours. As alternative the cumulative frequency curves of Air Temperature (better: Mean Radiant Temperature) during working hours can be adopted.



Percentage of time with 0.5>PMV>-0.5	
Percentage of time with 19<Ta<21 (Winter)	
Percentage of time with 25<Ta<27 (Summer)	

3.4. Multi criteria analysis

Proposed method

Variables:

C: Percentage of time with 19<Ta<21 (Winter) or Percentage of time with 0.5>PMV>-0.5

PE: Primary Energy Consumption reduction factor (in comparison to before retrofit situation or to reference building); desired value is 2

Overall Performance function:

$P = F_C \wedge F_{PE}$

$P = W_C * F_C + W_{PE} * F_{PE}$

Where:

Weights of Comfort and Primary Energy reduction can be assumed as

$W_C = 0.5$

$W_{PE} = 0.5$

Performance functions of Comfort and P Energy parameters

F_C = C/100

F_{PE} = 1 if PE ≥ 2

= 1-(2-PE) if 2> PE >1

= 0 if PE ≤ 1