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Monitoring protocol to assess the overall performance of lighting and daylighting retrofit projects

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Abstract

In the field of lighting and daylighting, standard monitoring procedures to assess the overall performance of retrofit projects are scarce. Nevertheless the access to monitored data is crucial to assess whether daylighting or electric lighting systems deliver the expected performance in terms of cost-effectiveness and energy efficiency. In order to bridge this gap, a monitoring protocol is under development as part of the International Energy Agency – Solar Heating and Cooling Programme (IEA-SHC) Task 50 'Advanced Lighting Solutions for Retrofitting Buildings'. The protocol focuses on lighting and/or daylighting (façade or roof) retrofit in the non-residential building stock. It covers four key aspects: energy efficiency, costs, quality of the lighting environment and user satisfaction. The main features of this protocol are presented in this paper, along with some lessons learned from the ongoing application on selected case studies.

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1. Introduction

The International Energy Agency – Solar Heating and Cooling Programme (IEA-SHC) recently launched Task 50 on 'Advanced Lighting Solutions for Retrofitting Buildings'. The main goal of this Task is to accelerate lighting and daylighting retrofit by using standard cost-effective methods applicable to a large share of the existing non- residential building stock. Task 50 is divided into four subtasks: A - market and policy, B - daylighting and electric lighting solutions, C - methods and tools and D - case studies. An additional joint working group "Lighting Retrofit Adviser" (LRA) aims to collect and harmonize the subtasks' outcomes. More information can be found online at http://task50.iea-shc.org.

The case studies assessment in Subtask D required a common framework for monitoring, analysis and comparison of the case study buildings. This framework was to focus on assessing the effectiveness of electric lighting and/or daylighting retrofit strategies in non-residential buildings. For this reason, it was desirable that case study buildings were available before and after the retrofit completion. In addition, the appraisal of the visual environment and user acceptance was to be evaluated alongside energy and cost-efficiency of the renovation.

A monitoring procedure developed in another IEA-SHC Task focused on assessing daylighting performance of buildings, including the users' perception of lighting quality [1–3]. Published standards, e.g. EN15193 and EN12464-1 in Europe [4,5], prescribe minimum requirements for both energy use and the luminous environment, but they cannot be considered as actual monitoring protocols. The ASHRAE 90.1 standard in the U.S. considers a performance path (in addition to prescriptive methods), where a building's performance is verified against a baseline, but the comparison is based solely on building energy simulations [6] and not on monitored data. A monitoring and verification procedure for retrofit of electric lighting systems has been proposed in the U.S., but it does not include daylighting and user satisfaction [7]. A general approach to performance measurement and verification of energy savings for new construction is offered by the International Performance Measurement and Verification Protocol® [8]. These existing documents, while not sufficient for the IEA-SHC Task 50 purposes, served as inspiration for the development of an initial monitoring protocol for testing and subsequent refinement during the Task 50 case study activities.

This article presents the skeleton for the monitoring protocol in its current state of development. The protocol has been discussed and further refined over the past two years by IEA-SHC-Task 50 experts, and it is currently being used within the Task for case study assessments in the 14 participating countries. New insights gained during the application of the monitoring protocol are used to continuously improve and update the procedures. The first part of this article depicts the general structure of the monitoring protocol. In the second part, more detailed descriptions of the procedural steps and the theoretical background are outlined. Finally, some lessons learned from the early application of this monitoring protocol to date are presented.

2. The protocol structure

The final monitoring protocol will serve as a guide for experts and non-experts, and describe a five-phase procedure for preparing and conducting the lighting/daylighting retrofit assessment. It consists of: 1) initial visit survey, 2) pre-monitoring decisions, 3) preparation, 4) monitoring and 5) analysis of results.

2.1. The initial visit survey

The very first step of the lighting retrofit evaluation should be the initial visit survey (IVS). The IVS objectives are to initiate contacts with the building management staff and collect basic information about the building, including geometrical data, identification of relevant spaces for monitoring, gathering of data about their function and occupancy patterns, definition of daylight and electric lighting zones in the selected spaces, retrieval of information about the daylighting and electric lighting systems used, as well as an indication about the time frame for the retrofit completion and its current state. Relevant for electric lighting and daylighting monitoring are spaces:
a) for which significant lighting and/or daylighting retrofit measures are being undertaken, b) which are representative of typical usage in the building, c) which are frequently used, and d) which represent an average or standard condition, e.g. the middle story in a multi-story building with identical offices. The IVS is supported by a data template in which the information is recorded.

2.2. The decision phase

In the decision phase the monitoring level and steps needed to conduct the actual monitoring process are established referring to the IVS data. Two distinct monitoring levels are proposed: a ‘basic’ and a ‘comprehensive’ level. The choice depends predominantly on practical constraints (e.g. access to the building), as well as on ambition, available time and budget of the monitoring team. The protocol is set up to have a full image regarding the lighting performance before and after renovation. However, it is possible to use just some segments of the protocol if only certain aspects of the renovation can be evaluated. The ‘basic’ level requires a) limited instrumentation (Table 1), b) access to the selected spaces in the building at least in their the post-retrofit condition, c) two specified days in a one-year period for the actual monitoring, d) approximately one year for the completion of the overall evaluation process (including the actual monitoring) (Figure 1).

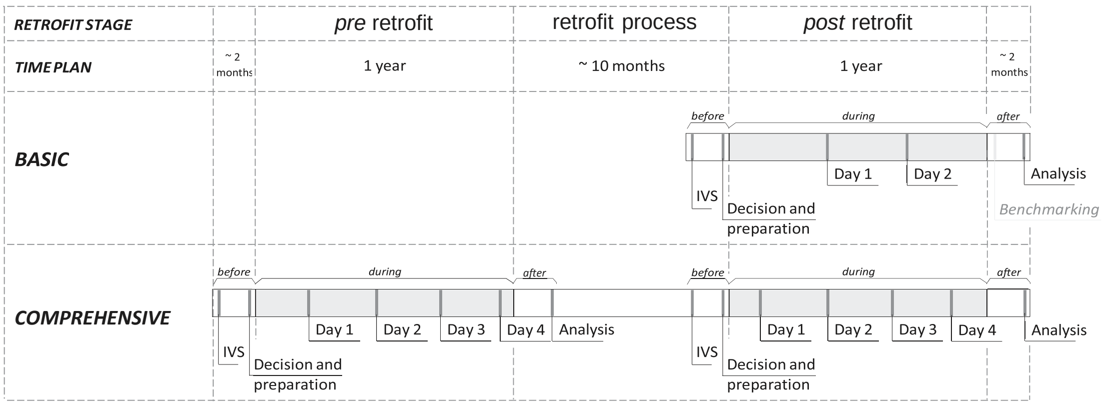

Fig. 1. Timeline for the evaluation protocol according with the two different levels of monitoring

The ‘comprehensive’ level requires a) advanced instrumentation, b) access to the selected spaces in the building both before and after the retrofit, c) four days per year over a period of two years for the actual monitoring, d) approximately three years for the completion of the overall evaluation process (including the actual monitoring). A description of the required instruments and their specifications are also provided in the final monitoring protocol.

In practice, a monitoring team might be contacted after a retrofit is completed. For this reason, the evaluation process suggested in the protocol also proposes comparing the post-retrofit monitored data with established benchmark values for a similar building type. In such cases, the ‘basic’ monitoring level is recommended. However, the basic monitoring level can also be applied when other requirements are lacking (e.g., instrumentation and/or available time or budget).

2.3. The preparatory phase

The preparatory phase consists of the specific planning and organization of the actual monitoring process for to the desired level. This involves planning of measurement dates or periods and acquisition and/or calibration of measuring instruments. A check-list indicating the required instruments and materials to bring will be proposed in the final monitoring protocol document.

2.4. The monitoring process

The monitoring program represents the core of the monitoring protocol. It covers four areas: 1) energy use, 2) retrofit cost, 3) photometric measurements, and 4) user assessment. The energy section addresses the measurement of electricity consumption for lighting and its control in the selected spaces. The costs section guides the monitoring team when collecting information about the cost-effectiveness of the lighting/daylighting retrofit. The photometric assessment provides an objective appraisal of the luminous environment based on measured photometric quantities such as daylight factor, illuminance, luminance, glare probability, luminance ratios, etc. The user assessment part focuses on subjective assessments, so it mainly collects data about the building occupants’ perception of the quality of the luminous environment and can identify potential problems which might not necessarily be obvious during the time monitoring takes place. In accordance with the chosen level of monitoring, the required monitoring dates and times, and the necessary procedures and data are determined (Table 1). A standard template is provided for data collection and further analysis.

Table 1. Required measurements for monitoring. For the 'comprehensive' level, consider the 'basic' level measurements plus the indicated additional assessments.

Level of monitoring	Basic	Comprehensive (in addition to Basic)
Monitoring periods	1 overcast day 1 clear day close to the equinox (±1 month)	1 clear day at summer solstice (±1 month) 1 clear day at winter solstice (±1 month)
Time of day	Morning/afternoon and night	=
ENERGY USE	Actual use of electricity for lighting	=
RETROFIT COSTS	Simple payback period or total cost	=
PHOTOMETRIC ASSESSMENT General and Luminance	Reflectance of room surfaces Glazing transmittance	Task position HDR [10, 11, 12] Spot luminance measurements
Illuminance	Exterior (global and diffuse) Interior in relevant spots Daylight factor	Grid of interior horizontal illuminances Horizontal illuminance on task Horizontal illuminance surrounding task
Glare	Observation (detection of sun patches or very bright surface areas, veiling reflections, …)	Task position HDR analysis (UGR, GDP) Vertical illuminance at the eye (adaptation)
Directionality	Observation Detection of shadows	HDR of perfectly diffuse white sphere [13,14] Cylindrical illuminance [5]
Color	Technical specifications of lamps and luminaires Comparison with color references	Correlated Color Temperature, Color Rendering Index, Spectral Power Distribution
Flicker	Observations	Detection with mobile phone [16] and/or rod-cloth [17], or oscilloscope, if available
View out	Photographs of main views View description Glazing-to-floor and glazing-to-inner-wall ratios Shading device description	Photographs of view from relevant task(s)
USER ASSESSMENT User survey	Informal interviews Questionnaire-based survey	Interviews (informal or semi-structured) Perceived lighting quality assessment [18,19]
Expert appraisal	Notes (max 500 words)	=

2.4.1. Energy use

If at all possible, the electricity consumption for lighting should be measured directly with a meter. Parasitic losses during standby, and for control systems and emergency lighting, must be included. As measurements can sometimes be difficult to conduct in practice, other appropriate means are suggested. The method of data collection and its reliability should be stated in the monitoring report. The measurements should be extrapolated to the whole year. When continuous logging is not possible, the measurement period may include three representative days during the year (close to an equinox, and the summer and winter solstices), but actual occupancy schedules (e.g. holiday periods) should always be considered. Some freedom is left in the determination of the measuring method, as long as the methodology is reported and the results reasonably represent the actual electricity use for lighting.

2.4.2. Retrofit costs

In practice, a lighting retrofit usually occurs in parallel with other building renovation measures. It might be difficult to isolate costs associated with lighting. Also, renovation costs are often kept confidential. It can therefore be hard to obtain figures for actual expenses. Nevertheless, the monitoring protocol emphasizes the vital importance of this information for assessing the pay-back period for retrofits and providing guidance to those considering undertaking a retrofit. Whenever possible, the total cost of the installation should be reported. When actual data are lacking, a cost estimate should be based on average market prices of the intervention (including materials and labor).

2.4.3. Photometric assessment

This part of the protocol focusses on the objective measurement of photometric quantities. In accordance with previous research (e.g. [9]), seven key metrics describing daylight and electric lighting quality are selected: luminance, illuminance, glare, directionality, color, flicker and view out. The measurements to describe each of these seven key metrics vary depending on whether the 'basic' or the 'comprehensive' monitoring protocol is applied (Table 1). A users' guide for the measurement campaign will be provided.

2.4.4. User assessment

The perception of the luminous environment in the monitored spaces is evaluated via survey questionnaires specifically designed for Task 50. The survey includes sections about the indoor climate, room appraisal, possible glare experiences, electric lighting and daylight, both in general and at the instant of the investigation. The expert appraisal by the monitoring team consists of a brief description of a visual evaluation of the space based on expert knowledge about lighting. It highlights the main strengths and weaknesses of the retrofit project and the likely impact of lighting measures on the users' well-being, as this information is hard to retrieve with concrete metrics.

2.5. The analysis phase

This section provides guidance on the interpretation of data. Gathered data are used for extracting meaningful results about the overall effect of the lighting and/or daylighting retrofit. Objective and subjective data for pre- and post-retrofit conditions (or post-retrofit and reference benchmark) are compiled, summarized and compared. How to select or create an appropriate benchmark reference is currently under debate within Task 50. Additional comments are provided from the 'expert appraisal'. The results of the analysis phase are collected in a further template, which communicates the results in a standard format to facilitate comparison with other retrofit projects.

3. Applications and lessons learned

The monitoring protocol is currently being tested on 24 buildings around the world, involving several monitoring teams. A constant feedback process ensures that the protocol is continuously being reviewed and modified based on actual experiences with using the protocol. Generally, the prescribed methods seem to work well, but minor adjustments are constantly made. To date, the monitoring teams have identified the following concerns for further discussion and revision:

- Since the monitored buildings are occupied, the monitoring dates are preferably determined and planned in advance. However, as monitoring is best performed under specific sky conditions (i.e. fully overcast and clear skies), this is often not possible. The issue should be addressed with the building manager, preferably already during the IVS, to allow for some flexibility in the monitoring schedules.
- Some of the measurements are time consuming and slightly intrusive for the building users. It is highly recommended to define a detailed plan of measurements in the preparatory phase.
- While actual lighting energy use data are always best, electric lighting circuits are not provided with a separate electricity meter in most buildings. The Task 50 monitoring teams are testing different means to measure the real consumption, without relying upon calculation methods.
- Some measurements require significant familiarity with methodology and instruments. The Task 50 experts are considering providing a 'measurement manual', most likely in an appendix to the monitoring protocol.
- Unpredictable events might change the assessment plan during any field measurements. Alternative plans should be considered.

- Monitoring procedures can interfere with expectations of privacy and confidentiality for both building owners and users. Such concerns should be discussed when initiating a monitoring process and agreement about how to treat potentially sensitive data should be reached. Agreements in writing with building owners and users are best.

The ongoing case studies show that substantial differences in pre- and post-retrofit conditions can be identified by the monitoring process. The user assessment part is identified as a key component for understanding the impact of the luminous environment on building occupants, and thus the success or failure of a lighting retrofit. While user assessments often support what has been identified by measurements during the monitoring periods, they can also highlight additional positive and/or negative aspects of the respective lighting scenarios which have occurred outside the monitoring period, such as seasonal problems or special moments which provide delightful experiences in a space. The appraisal of the situation by a lighting expert also provides a more a complete picture of the situation, which is sometimes difficult to determine with objective photometric values and simple on-site observations.

4. Conclusions

Assessing the effect of electric lighting and daylighting retrofits in a building can be difficult because of the potential complexity of the spaces and technology, as well as the variability of lighting and usage conditions. A standard monitoring protocol was developed as part of IEA-SHC Task 50 with the aim to support expert as well as non-expert monitoring teams involved in retrofit assessments. It considers both objective and more qualitative, subjective assessments. The approach taken with the monitoring protocol and the associated procedures allows for the presentation of objective, quantifiable data on the actual performance of the daylighting and electric lighting systems before and after a retrofit, and linking these data with user experiences associated with the resulting luminous environment. Ongoing test applications of the monitoring protocol in Task 50 case studies ensure that the monitoring protocol is sufficiently robust before its release to the public. The detailed procedures and guidance also permit those undertaking monitoring to predict the time and budget needed. It also allows for better planning and coordination of the monitoring procedure with the building owners and managers.

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