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A toolbox to evaluate non-residential lighting and daylighting retrofit in practice

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A B S T R A C T

In the field of lighting and daylighting, standard monitoring procedures to assess the overall performance of retrofit projects are scarce. Nevertheless, access to monitored data is crucial in assessing whether daylighting or electric lighting systems deliver the expected performance in terms of cost-effectiveness, energy efficiency and lighting quality. In order to bridge this gap, a lighting retrofit evaluation toolbox was developed as a part of the International Energy Agency-Solar Heating and Cooling Programme (IEA-SHC) Task 50: "Advanced Lighting Solutions for Retrofitting Buildings". The evaluation toolbox focuses on non-residential buildings and covers four key aspects: energy efficiency, costs, quality of the lighting environment and user satisfaction. This article presents the main features of this evaluation toolbox, along with some lessons learned from its application in selected case studies.

1. Introduction

Lighting accounts for about 20% of global electricity consumption, or roughly 3000 TWh/year [1], which corresponds to 0.54% of the world gross domestic product [2]. Predictions from 2006 warned of the risk for an increase of 1250 TWh/year in lighting electricity use by 2030 if policies were not changed [1]. Over and above this, 1.3 billion people (18% of the world population) still have no access to electricity and, thus, electric lighting [3]. The world's growing population and growing access to electricity will increase the global energy demand, despite improved efficiency of lighting systems. In contrast, the European energy demand for indoor lighting in residential applications is actually reducing [4] due to the combination of energy policies, the profitability of lighting retrofit as an energy conservation strategy [5] and the introduction of efficient LED lighting. The global growth of energy demand for lighting can actually be contained by using best practices. Moreover, while energy efficiency is probably the strongest driver for lighting retrofits, the lighting community is also addressing the need for lighting quality [6].

In this context, the International Energy Agency-Solar Heating Cooling program (IEA-SHC) conducted its Task 50: "Advanced Lighting Solutions for Retrofitting Buildings" from 2013 to 2015. Task 50 aimed to demonstrate different daylighting and electric lighting retrofit possibilities in non-residential buildings through best-practice and cost-effective solutions. The Task 50 activities were organized in four different subtasks:

– Subtask A: "Market and policies", to identify key numbers in relation to the cost-effectiveness of different lighting retrofit approaches;
– Subtask B: "Daylighting and electric lighting solutions", to appraise existing and new lighting technology;
– Subtask C: "Methods and tools", to assess existing computer-aided design tools and to identify the stakeholders' needs for new tools;
– Subtask D: "Case studies", to show lighting retrofits to decision makers and designers and to evaluate daylighting and/or electric lighting retrofit solutions in practice.

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Subtask D required a common framework for the monitoring, analysis and comparison of the different case studies.

When Task 50 started, monitoring procedures for electric lighting and/or daylighting retrofit evaluation were almost non-existent. A monitoring protocol developed in IEA-SHC Task 21 focused on assessing daylighting performance of buildings, including the users' perception of lighting quality [7–9]. Published standards, such as EN15193 and EN12464-1 in Europe [10,11], prescribe minimum requirements for both energy use and the luminous environment, but they cannot be regarded as actual monitoring protocols. The ASHRAE 90.1 standard in the USA considers a performance path (in addition to prescriptive methods), through which a building's performance is verified against a baseline, but the comparison is based solely on building energy simulations [12] and not on monitored data. A monitoring and verification procedure for retrofit of electric lighting systems has been proposed in the USA, but this neither includes daylighting nor lighting quality [13]. Meanwhile, a protocol focusing on lighting quality was published in 2014 by the International Commission on Illumination (CIE), when this toolbox was already under testing [14]. The CIE protocol was drafted in parallel to the toolbox presented here. Interestingly enough, the approaches selected by the CIE and Task 50 were very similar (see e.g. two levels of monitoring and focus on objective and subjective lighting quality, see Section 2). However, the CIE protocol does not consider the energy efficiency and retrofit costs. Finally, a general path to performance measurements and verification of energy savings for new construction is offered by the International Performance Measurement and Verification Protocol® [15]. These existing documents, while not sufficient for the purposes of IEA-SHC Task 50, served as inspiration for the development of an initial monitoring procedure for testing and subsequent improvement during the Task 50 case study activities.

This monitoring procedure was discussed and further refined over the past two years by IEA-SHC-Task 50 experts, and has been used within the Task as a toolbox for case study assessments in the 14 participating countries. New insights gained during its application were used to continuously improve and update the methodology. The toolbox presented here is the final assessment procedure used for the case studies in Task 50. The first part of this article explains how the toolbox was developed. The monitoring procedure itself is then described, along with some theoretical background and hints for data interpretation. Finally, the article presents some lessons learned from actual applications of the monitoring procedure, suggestions for future development, as well as important conclusions.

Please note that the Task website (http://task50.iea-shc.org) will provide a non-expert user guide, which includes, among others, a checklist for the required equipment and instructions on how to perform the measurements in practice. This paper does not provide examples of the cases where the monitoring toolbox has been applied and how to interpret and analyse the monitored data in detail, nor does it provide any picture, illustrations of actual cases. These can be found in the freely available "Lighting Retrofit Adviser" (LRA) source book published at the conclusion of IEA Task 50.

2. Methodology

During the first year of the Task 50 activities, the experts

- investigated publicly available monitoring protocols for lighting retrofits (see summary in Table 1),
- performed an extensive scientific review on daylighting and electric lighting retrofit strategies, and
- collected relevant information from lighting business actors during the task meetings.

Firstly, as far as we could ascertain, no comprehensive monitoring procedure including both daylighting and electric lighting retrofits was available when Task 50 was initiated.

Secondly, the scientific literature review [16] revealed, among other things, that:

- Simulation results tend to overestimate the saving potential, especially concerning the use of lighting control systems;
- Besides electric lighting technology upgrades, strategies to reduce energy use without compromising lighting quality include the use of task-ambient lighting, reduction of maintained illuminance levels and improvement in spectral quality of light sources;
- Occupant behaviour has a large impact on the final energy use, in some cases larger than the technological solutions.

The Task 50 experts met every six months to discuss progress and exchange. Each meeting included a half-day industry workshop with lighting stakeholders, public administration and design firms. On these occasions, it was clearly emphasised that a lighting retrofit should be cost-efficient while ensuring an improvement in the lighting environment, for example making it easier to perform tasks or providing an identity to the space (such as in a company's headquarter).

The outcomes from the review and meetings suggested that a daylight and electric lighting evaluation toolbox has to be based on four aspects: energy use, retrofit costs, photometric assessments and user assessments (Fig. 1). The metrics used to evaluate each aspect should, as far as possible, be based on measurements and user surveys on site. The choice of the metrics was based on published scientific literature and standards, as reported in Section 3.4.

The monitoring campaign was launched during the second year of Task 50. However, the initial procedure was judged too expensive in terms of time and required manpower. Thus, two levels of monitoring were subsequently proposed: a basic and a comprehensive monitoring level. It was decided to provide a guide for planning the monitoring, consisting of a 5-step procedure: (a) the initial visit survey, (b) the decision-making phase, (c) the preparatory phase, (d) the monitoring process and (e) the analysis phase (Fig. 2).

The entire monitoring procedure was continuously refined and streamlined keeping the format of the four aspects and the two levels of monitoring.

The monitoring procedure was tested in 19 buildings around the world, involving several monitoring teams. The buildings had different space destinations (e.g. office, sport/recreation, educational, industry). Some underwent only electric lighting retrofit, such as luminaire or lamp replacement to more efficient ones, changes of correlated colour temperature of the source, use of advanced lighting controls, and rearrangement of the light fixtures scheme. Other were retrofitted by using both daylighting and electric lighting strategies, e.g. renovation of façade, use of new shading systems, and improvement of inner surface reflectances. Finally, other projects underwent a total renovation, which also included lighting retrofit [17,18]. The testing followed either the basic or comprehensive procedure, according with the teams' resources.

Based on their actual experiences from first monitoring attempts, the teams discussed issues which arose with some of the monitoring metrics:

- Information redundancy: during typical monitoring, the metric did not provide essential additional information about the lighting retrofit;
- Time inadequacy: compared to the information gain, the metric required too much time to be assessed;