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SBE19 Milan “Resilient Built Environment for Sustainable Mediterranean Countries”

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Preface

The SBE19 Milan “Resilient Built Environment for Sustainable Mediterranean Countries” is an International Sustainable Built Environment Conference, organized by Politecnico di Milano in the framework of the Sustainable Built Environment (SBE) series of conferences.

Being within the SBE series, this event gathers the support of CIB – International Council for Research and Innovation in Building and Construction, iiSBE – International Initiative for a Sustainable Built Environment, the United Nations Environment Programme, and FIDIC – International Federation of Consulting Engineers. The goal of this series of regional and international conferences is to disseminate innovative policies and developments in the field of sustainable urban environment to a broad international audience of specialists in policy, design, construction and operation of buildings and related infrastructure.

The SBE19 Milan proceedings deals with the main topics of the conference, covering important items to support Sustainable Built Environment for Mediterranean countries: Environmental issues relevant to the Mediterranean region and adopted policies, programs regulations and standards within the regional context; Resource efficiency at the building, district and urban level; Innovation in materials, products and systems; Environmentally efficient materials and products and sustainable use of materials; Methods, tools and certification; Renovation and performance upgrading of the built environment; Integration of renewable energy at building and small urban area scales; Issues related to zero and nearly-zero operating and lifecycle emission performance; Cost, financing and taxation for high performance , Economic and social externalities; Training and education to promote adoption of sustainable approaches; ICT for a Sustainable process management.

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Active House and user-friendly visualization of sensors' monitored data: VELUXlab, a real cognitive and smart NZEB prototype

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Active House and user-friendly visualization of sensors' monitored data: VELUXlab, a real cognitive and smart NZEB prototype

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Abstract. European standards had already set Nearly Zero Energy Buildings (NZEB) as the current and mandatory goal for the construction market. Thus, several design strategies have been developed, in order to define the best practices towards NZEB targets: high performances of construction components, integrated with high energy-efficiency solutions for building systems. The Active House Vision and evaluative approach on buildings summarize the current protocols, accounting the three principles of Comfort, Energy and Environment to parametrically design and assess buildings until their “as-built” status. However, at that point of the design process, this evaluation relies mainly on design simulations, which do not properly consider the occupants' component, resulting in a gap between forecast and real performances. Since predictive models of users-building interactions are underway, the paper focuses on the building operation stage of existing and validated NZEBuildings, addressing the performance-gap as related to the final users' mismanagement of the building system (envelope and installations). Referring to cognitive buildings as sensors-equipped and smart Active Houses, the method proposes a user-friendly visualization of (big) real-data as a possible solution for the final-user training and awareness. This approach has been applied to the case study of VELUXlab, a real building prototype of Politecnico di Milano, already validated as the first Italian NZEB inside a university campus and “as-built” Active House. The outcomes of the paper enhance the potentials of the current knowledge and design practice to achieve a sustainable and healthier built environment, looking at the future but working today.

1. Introduction

The most recent European Directive [1] has once again confirmed the warning scenario of our building sector according to its environmental impact, with 40% of energy consumptions and 36% of GHG emissions related to the European construction market [2] [3]. These numbers have set the need of the Nearly Zero Energy Building (NZEB) definition [4], and its prescription as a mandatory building requirement by 2020, representing, therefore, a common and shared strategy for our built environment towards the UN's Sustainable Development Goals.

However, the NZEB concept [2] generally frames holistic strategies and best practices, relying – during the design phase and the “as-built” status – on static and dynamic simulations to verify the related building performances. This process reflects, indeed, mainly the interaction between the outdoor/indoor climate conditions and the construction components, overcoming an important factor for the building global behavior: the final user. Retrieved data has shown that the highest levels of energy consumptions are registered during the operational phase [5] [6] [7], when the “occupants-building interaction” plays a fundamental role, showing a gap between the forecast and measured performances of the building



global system. This gap could be addressed to different factors: within the simulation models of the design phase, a mis-consideration of (i) the occupancy profile or (ii) the real users' behavioral drivers that could describe the realistic users-building-environment interaction [8]; or (iii) to a mismanagement of the building during its operation. Since predictive models of users-building interactions are already underway¹ [8], this paper focuses on the building operation stage of existing and validated NZEBuildings, addressing the performance-gap as related to the final users' mismanagement of the building system (envelope and installations). As in the automotive sector, indeed, also in constructions the real user - different from the virtual/forecast one - needs a guide towards efficient uses of the real product to guarantee the predicted and assured performances.

Moreover, for NZEBs, which are defined by high performances of construction components, integrated to high energy-efficiency solutions for building installations, the performance-gap could represent even a bigger issue, precisely because of the high levels that their definition requires [8].

The proposed building design and management method aims to a possible solution: at first, with the application of a user-centered design strategy and practice that has already lead to NZEB examples – the Active House (AH)² approach [9]; then, the user-friendly visualization of data, retrieved and mined lively from the monitoring survey of a real NZEB operation performances. The proposal is applied, indeed, to a real case study, already validated as NZEB and “as-built” Active House: VELUXlab, a cognitive smart building prototype of Politecnico di Milano. The application to a real building prototype guarantees both to test the proposal effectiveness and to further adopt a reverse engineering design strategy as a practical way to better qualify/describe the relation environment-building-user.

2. Methodology

In the construction practice, even the most advanced one – towards NZEB definition, the performance-gap is one of the real issues to face. This paper aims to propose a final-user training approach, through a user-friendly and smart visualization of data, in order to fill the range of the gap that refers to occupants' mismanagement of buildings components and systems.

Since the focus is the operation phase of the building process, the followed method had to refer to real constructions, here considered as sensor-equipped, smart, and cognitive buildings, able to collect quantitative data about their behavior and interaction with the occupants, and even actively reply to the latter one. This mechanism is already possible when considering Active Houses, since these demo-buildings are already users-oriented designed; moreover, the AH evaluation approach already defines a tool – the AH Radar – that gives a visual interpretation of (simulated) data, according to the three principles of Comfort, Energy and Environment [15].

Within the Active House evaluation pattern, therefore, this study decides to focus on specific physical quantities, used to define the building behavior in simulated scenarios, and able to provide real-time conditions about internal comfort (at first), when related to monitored environments. Thus, inside these smart and cognitive buildings, the installed devices measure:

- CO₂ concentration [ppm];
- Air temperature [°C]: indoor air-temperature³;
- Relative Humidity [%];

¹ The referenced paper [8], indeed, describe the impact of the occupants' component through a set of different simulation scenario, taking into account several combination of users' action drivers; the simulated environment is exactly VELUXlab, the same case study of this work, presenting the paper consecutively with the previous one.

² The Active House [10] Vision represents a well-established example of NZEB-driven design guideline [11] [12] that summarizes the current most recent and widespread protocols for building evaluation [15]. It is based on three principles, Comfort, Energy and Environment, which resume quantity parameters that are able to describe the building behavior.

³ The authors would like to underline that this work does consider the Air-Temperature instead of the Operative Temperature (much more appropriate, while discussing about users' comfort) because it was not possible to have direct measured data, through the installed sensors; however, according to the scope of the paper, it has been sufficient to evaluate the Air Temperature values actually retrieved by the installed sensors.

- PM2.5 and PM10 [$\mu\text{g}/\text{m}^3$];
- VOC concentration [ppb];
- Light levels [lux];
- Noise [dbA].

The collected data from a wireless network of sensors are so stored in a central server, mined and visualized into three different way of dialogue with the final user: (i) a live AH Radar plot (figure 1), computed in real-time, according to the AH Specification [12]; (ii) a live web-dashboard (figure 2) and (iii) a live app-dashboard (figure 3), for a dynamic and real-time interaction.



Figure 1. An example of the Active House Radar [12] visualization, as derived from monitoring data (in light green); in the background, the “as-built” calculation plot (in light red), obtained within a simulated environment. The radar grid reflect the AH evaluation method [10] [11] [12].



Figure 2. An example of the live web-dashboard (retrieved from <https://dashboard.cphsense.com> and elaborated by the authors).

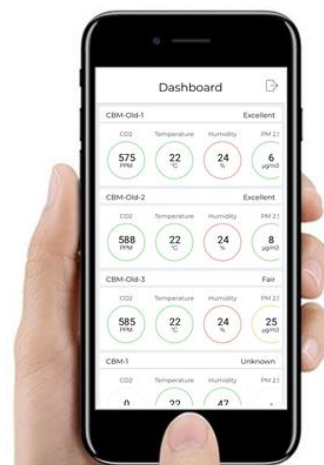


Figure 3. An example of the live app-dashboard (retrieved from AmbiNode app on TestFlight and elaborated by the authors).

This dynamic method could be applied not only to the operational phase but also to the design phase of the building process, giving, therefore, information about the building for its entire life-cycle. The dynamic radar, indeed, is a suitable way to visualize the different design options that are considered from the first concept to the “as-built” definition (figure 4), allowing the design team to evaluate them into a holistic perspective, through the principles and criteria of the AH Vision.

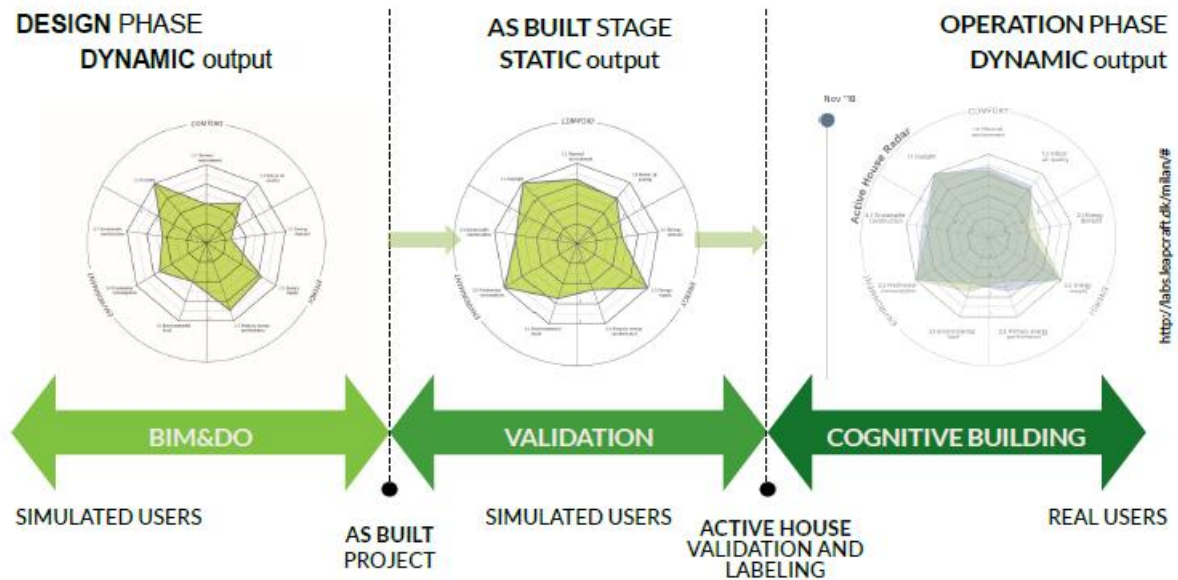


Figure 4. The visualization of the entire process that follows the building life-cycle: (i) a dynamic output of the AH Radar for the Design Optioneering process; (ii) a frozen output showing the validation at the “as-built” stage, and representing the milestone of the achievements with real products; (iii) the cognitive building dynamic AH radar output, where the validation is computed on real monitored data, through sensors.

Finally, this approach brings up the case study of VELUXlab, a real smart building prototype of Politecnico di Milano, already validated as the first Italian NZEB inside a university campus [13] and “as-built” Active House [14].

3. The case study: VELUXlab, the first Italian NZEB and Active House of a University Campus
VELUXlab (table 1 and figure 5) is the first Italian NZEB located inside a University campus as a retrofitted demo-house realized by VELUX and conceived as an Active House already in 2012 [13]. In 2017, it has also been labeled as the first Italian Active House certified “as-built” [9] [14].

Table 1. Main features and technical characteristics of the case study.

VELUXlab		
Project data	Location	Milan
Roof	Transmittance (W/m ² K)	0,133
	Damp effect (h)	10,5
Envelope	Transmittance (W/m ² K)	0,124
	Average FLD (%)	5,7
Transparency	Transmittance (W/m ² K)	1,1

As it is, one of the most important features of the buildings is the possibility to remotely control the opening/closing of skylights and shading system (solar blinds and roller shutters), both via schedules and time by time, according to users' needs of visual comfort, indoor thermal environment and fresh air circulation. Whenever the envelope needs to have an adiabatic behavior, the installations integrate the global response, through the HVAC systems (activated according to monitored CO₂ concentration) and the heating/cooling system, which is turned off/on according to determinate back points and set points [8].



Figure 5. VELUXlab at Politecnico di Milano, Bovisa Campus - Designed as the demo-house ATIKA, by ACXT/IDOM studio for VELUX, in 2011; retrofitted by Atelier2 – Valentina Gallotti and Prof. Marco Imperadori – Politecnico di Milano (credit: Politecnico di Milano)

As related to this experiment, the lab has been equipped (as illustrated in figure 6) with three sensed devices, the AmbiNodes by Leapcraft, interconnected via a Wi-Fi network, and able to measure and record all the data that are necessary to understand the impact of building management on indoor climate and comfort perception (as previously listed).

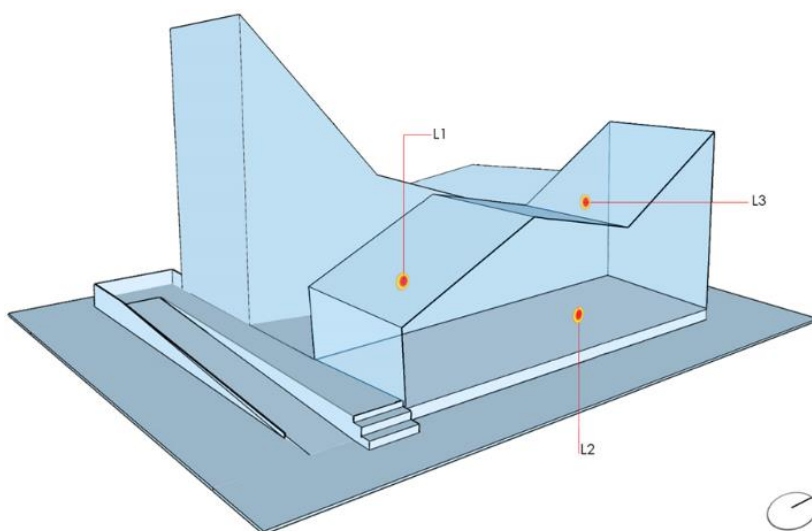


Figure 6. The localization of Leapcraft sensors in the eastern wing of the lab, as three of the many devices that are operating inside VELUXlab [16]. The latter ones are used in order to attest the reliability of AmbiNodes devices, during this experiment (credit: Politecnico di Milano).

The location of sensors across the room traces the different areas where tenants could affect more the building behavior, in terms of Comfort parameters (CO₂ concentration, daylight, and air temperature regulation by windows openings):

- L1 is located in the southern space, over the meeting desk under three openable skylights;
- L2 is over the workstations, in the middle of the space, where people meanly stau all day long, working on a computer station;
- L3 takes a higher place, above the second meeting desk and workstations.

According to this configuration, VELUXlab is defined as a really smart and cognitive building, able to read the occupants' presence, interact actively with them – through the derived and re-elaboration of measured data – and adapt itself (the envelope and systems components' activation) to users' modifications on the indoor climate.

4. Results and discussions

The so-defined monitoring campaign started in December 2018 and it is still ongoing.

The visual outputs of the monitored scenario allow getting information from data about:

- the live situation and performances, through the live dashboards on web/app devices, alerting the final user when every single parameter is going out of the defined range for indoor comfort quality (figure 3);
- the historical trends, whose data are collected on a cloud database and could be mined by the user (figure 7) or the building manager and/or the designer, to understand the human factor impact upon building behavior;
- the AH holistic evaluation of the building, assessing also the impact of the occupants' actions⁴ on building components on all the parameters of the AH Radar (figure 8).

At first, the selected graphs on figure 7 show that, after a settlement period for all the sensors, the recorded data are almost cyclic, mirroring the cyclic use of the building during its operation.

Moreover, considering the high and attested soundproof performances of the building envelope [13], the Average Noise graph could represent a coding of the users' presence inside the room, where lower values stand for empty indoor space. Then, the same inflections are easily visible on the upper graphs: the Average Temperature and the Average Light data-plots. In particular, on the first graph of figure 7, the temperature peaks show the free contribute to heat gains when people are using the lab spaces. The latter, instead, shows the set-schedule for the shading system automatic operation (opening at 9 a.m. and closing at 8 p.m. every day, except the weekend, when the lab is closed), implying a direct impact on indoor environment conditions.

⁴ The users are able to control remotely the opening and closing of the windows, the solar blinds and roller shutters, in order to regulate natural daylight income, solar heat gains that increase the indoor temperatures and fresh air [8] [14]

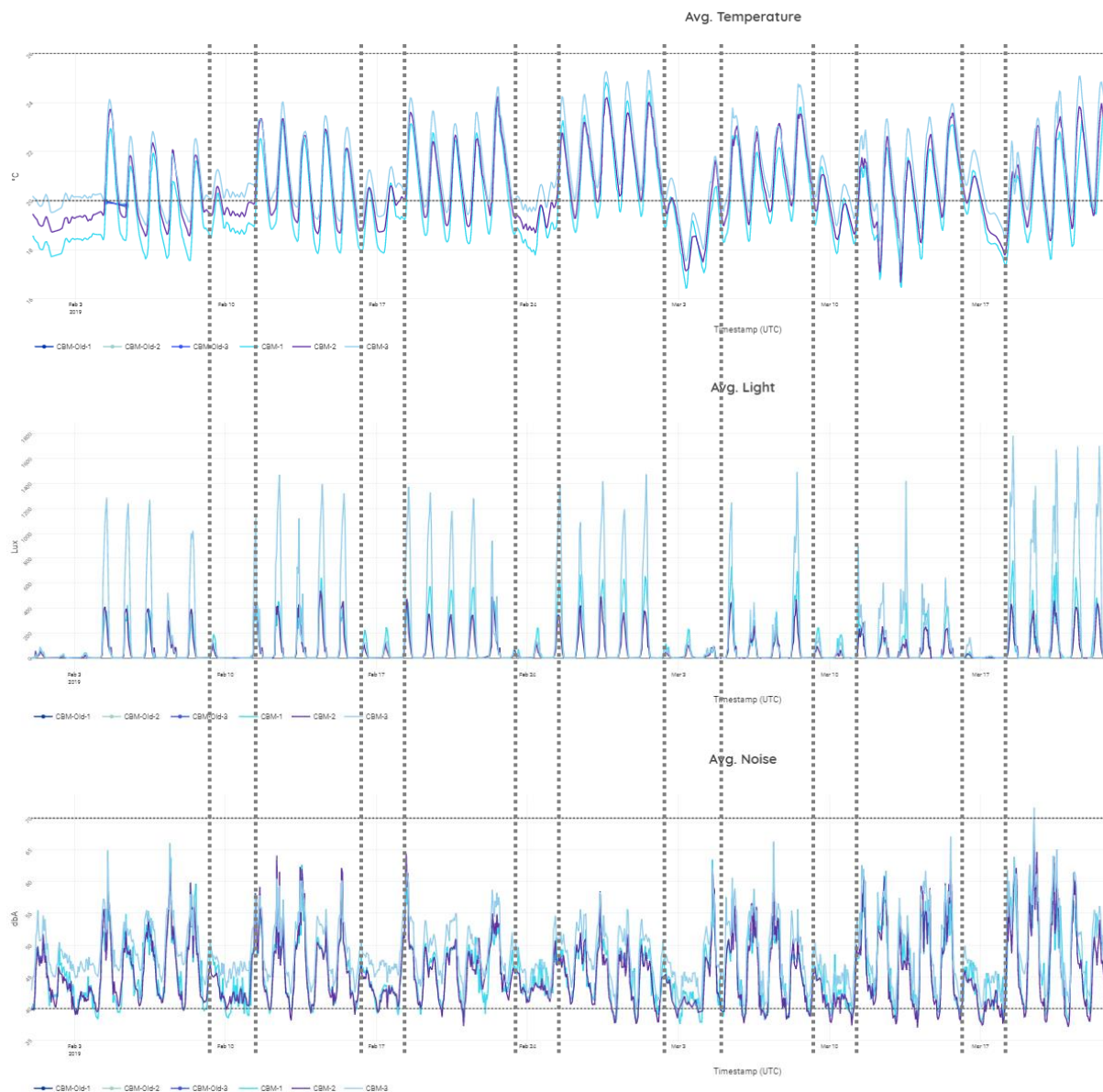


Figure 7. A selection of three historical graphs showing the trends – between February and March 2019 – of: (i) average temperature [°C]; (ii) average light distribution [Lux]; (iii) average noise [dbA]. Retrieved from: <https://dashboard.cphsense.com/28/historical/>



Figure 8.a Three of the monthly active graphs retrieved from the live AH: Dec 2018.



Figure 8.b Three of the monthly active graphs retrieved from the live AH: March 2019.



Figure 8.c Three of the monthly active graphs retrieved from the live AH: April 2019.

In the end, the comparison between different stages of the Active House Radar plot (freezing the dynamic live graph at three different moments, as in figure 8) brings up further interesting considerations, focusing especially on the variations of the Thermal Environment (TE) and Indoor Air Quality (IAQ) parameters:

- in Dec 2018, the TE higher level reveals the adiabatic strategy of the building, which relies mainly on the construction components performances for the heating season; at this time, the users' interaction with the building is scheduled – and imposed – to be minimal (no windows operation and shading system always open for solar gains);
- in March 2019, the outdoor climate conditions impose users to interact with the building, since the outdoor temperature values allow direct thermal exchange between indoor and outdoor, via natural ventilation through openable windows and skylights. By controlling the opening/closing of the windows and the related shading systems, the occupants start to get the control of the building functioning, according to the Comfort drivers of a good thermal environment and fresh air. In this case, a bigger (than expected from simulations) consumption of energy for systems' operation guarantees the high levels of TE and IAQ, reflecting the low resiliency of users to interact with the building in the most proper and energy-efficient way, and causing the energy efficiency performance-gap;
- in April 2019 the last AH Radar shows, instead, the users are more confident with the smarter operation to optimize the energy consumptions with the indoor conditions for comfort, as reported in the schedules of operations of windows remote-control. Here, they are indeed able to exploit as maximum the high performances of the NZEB, when considering the Primary Energy Demand⁵.

5. Conclusions and further developments

This analysis is a preliminary step into the investigation of the interaction between users and building systems, especially focusing on the operation of real NZEB prototypes.

However, few considerations have to be done, like the need of an efficient data mining process as a base step for the managing of this volume of data, and the importance to concern the final users' privacy while collecting data about their attitudes and behavior.

In the end, beyond the current purposes of the research, this application has given also the opportunity to easily monitor the building performances checking the reliability of other older sensors that were installed during the construction phase, on envelope and HVAC system. Indeed, the newer devices have revealed that the CO₂ concentration was always on levels a lot higher than the same ones registered by the sensors which control the system operation, causing a worst indoor air quality condition and a misuse of the HVAC system itself.

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Conflict of interest: The authors declare no conflict of interest.

⁵ Please consider that the Primary Energy Performance indicator of the AH Radar is capable to reflect only the performance of the building into cover the Energy Demand with renewable resources, such as solar panels, PV systems and district heating (in its renewable part); at the moment, the calculation are not considering the free solar gains as part of renewable heating resources [11] [12].

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