INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY COMPREHENSIVE RESEARCH

Design and Simulation-Based Evaluation of a Photocell Based Automatic Lighting Control System for Household Energy Saving

Ali Jawad [1*], **Ruqaya Raad Abdulzahra** [2], **Noor Al-Huda Raad Khudair** [3], **Masar Muthaffar Sameer** [4], **Ruqaya Amjad Munshid** [5]
[1-5] Department of Medical Physics and Radiotherapy, Technical Engineering College, Sawa University, Almuthana, Iraq

* Corresponding Author: **Ali Jawad**

Article Info

ISSN (online): 2583-5289
Volume: 05
Issue: 01
Received: 12-11-2025
Accepted: 11-12-2025
Published: 10-01-2026
Page No: 01-10

Abstract

Household lighting is frequently managed wrongly due to user forgetfulness and no daylight-aware control, leading to unplanned electricity use. This work is dedicated to the design and simulation-based investigation of an inexpensive automatic lighting control system based on the photocell sensor to adjust the operation for ambient illumination. The architecture of the proposed system is an illumination sensing stage, a control logic module, and an output-switch interface to transfer the light loads within the house.

The control strategy employs threshold-based decision rules with hysteresis and a highly customizable time-delay to minimize switching speed due to light variations, allowing for operational stability. Since no field setup happened, the performance of the system is analysed with a scenario-based analytical model. Using a power–time formulation, energy consumption is estimated, and a baseline profile of manual energy consumption is compared with the expected automated control across representative environments in the household (e.g., varying daylight availability, window exposure, etc.). A sensitivity analysis is provided to explore the effect of certain parameters (lighting threshold, delay time, lamp power rating, etc.).

The results show that automated daylight-aware switching can reduce avoidable lighting operation, realize significant energy saving promise under widespread use habits, and remain simple and low implementation cost. Finally, the study concludes with a tangible cost and payback discussion and a plan for potential work towards real-world validation and greater sensing (e.g., occupancy integration).

DOI: https://doi.org/10.54660/IJMCR.2026.5.1.01-10

Keywords: Photocell, Automatic Lighting Control, Daylight-Aware Switching, Energy Saving, Household Electricity, Simulation-Based Evaluation

1. Introduction

Households’ energy-saving efforts continue to be a key pathway towards reducing electricity use, and lighting is one of the most flexible end-uses due to its ability to be affected by both technology and user behaviour. Demand for residential lighting is highly correlated to daylight supply (i.e. season, latitude and daily daylight hours) and thus daylight-aware strategies can be applied to homes. For instance, in a regression case by Norwegian households, the value of annual household lighting electricity was estimated to be at around 1050 kWh/year and lighting accounted for approximately 6% of total household electricity use, emphasising both the importance of lighting as well as its daylight dependent nature [1].

In addition to optimal lighting, lighting controls can save electricity by operating a light only when necessary, and only to that level. In an extensive review of published literatures on lighting-controlling systems (in commercial buildings but also used in common practice as a benchmark for control effectiveness) reported average savings of approximately 24% for occupancy-based control and approximately 28% with daylight reacting control studies.

The same study also underlined an important limitation in method: simulation-based studies generally overestimate daylighting-control savings (by >10%) relative to true installation performance due to effects of commissioning quality, sensor position, user interaction, and operational limitations [2].

This is one of the most important concepts when an evaluation is modeling rather than field measurement. Daylight control systems (commonly referred to as daylight harvesting systems) apply a photosensor to modulate electric lights based on available daylight in order to achieve a desired illuminance and minimize avoidable lamp output. In the literature review of daylight harvesting systems, the energy-saving ability was generally in the range of 20–60% of that experienced in non-dimmed installations, but also observed that performance can be highly variable as a result of technical robustness, architectural integration, commissioning and human acceptance problems [3]. For the field monitored controlled conditions, daylight control has also been found to provide significant — but case specific — savings – a full-year monitoring study of three different daylight-control configurations employed in comparable classrooms experienced annual savings of anywhere from 18% to 46% and directly compared these differences with regard to type of control, sensor configuration, and commissioning standards [4].

One of the critical technical differences on photocell-based control has to do with the decision between open loop vs closed loop sensing. In the case of open-loop control, a photosensor must be oriented to record daylight (no feedback coming from the controlled luminaires), but the closed-loop sensor “can see” both daylight and electric light output, which acts as a feedback loop that could assist in improved regulation while also introducing considerations for placement and reflection [4]. Furthermore, in practice, some non-ideal factors such as auxiliary (parasitic) power input by sensors/controllers and real dimming details of ballasts as well as LED drivers should be taken into account which may reduce net savings in comparison to theoretically idealized values [5].

Therefore, low-cost photocell automatic lighting system and solution for home is addressed in this paper, and structured evaluation is conducted without the need of creating physical prototype or for field trials. We address, in the paper, (i) a simplified system structure for a photocell based automatic lighting controller (i.e., architecture, components, and control logic), and (ii) simulation based analysis in setting limits (such as, different daylight availability, operating hours, setpoints, and users’ schedules), to approximate the potential electricity savings under the existing control methods while explicitly incorporating the limitations in previous studies [2]. This particular approach is meant to facilitate decision making by helping to understand if even a basic daylight-only controller would yield meaningful household energy savings if and when realistic assumptions were met.

2. Literature Review

Electricity savings from lighting controls are consistently documented in literature, yet any savings may be significantly contingent upon the control strategy (manual switching vs. automatic on/off vs. continuous dimming), daylight provision, commissioning quality, and user behaviour. A substantial meta-analysis of field and case-study evidence demonstrates the potential of lighting controls, in particular occupancy-based and daylight-responsive controls, to provide significant average savings as well as finding simulation savings substantially overestimate real-world effects when commissioning and human factors are ignored [2].

Daylight-linked controls are particularly applicable for photocell-based systems due to the fact that they are designed to maintain a target illuminance by reducing electric lighting when daylight is available. A review-based design recommendation guide that daylight harvesting systems can deliver significant savings, but are sensitive to the installation of sensor locations, calibration, zoning, and user acceptance [3]. Field-monitored results in large atrium spaces indicate significant savings from the daylight-linked systems, though installation/commissioning problems and sensor placement errors can considerably limit their efficacy [6].

Comparative studies in office contexts demonstrate differences in savings for different control systems and that actual consumption can be greatly influenced depending in part on how an occupant engages with the system. Simulation-based and measurement-based studies of energy savings across control methods emphasize that energy savings can be wide depending on the orientation, daylight conditions, and the logic of the control, indicating the necessity of a precise control strategy when designing an indoor control system [5]. Likewise, a monitored case study of a lighting control system in an office reports savings while also highlighting parasitic power (sensor/controller power) in net estimate of savings [7].

Another major consideration is the behavior of the space being occupied. Studies from monitoring have discovered that lighting power consumption can be significantly increased as the result of habitual activities (for example, turning lights on upon first arrival, irrespective of daylight conditions), and automated dimming tactics can also bring down energy consumption when properly engineered and applied [8]. These results suggest that a photocell-based household lighting concept requires an explicit statement of (1) the control logic (on/off vs. dimming), (2) sensor positioning and calibration assumptions, and (3) how user interaction is governed (override, delays, hysteresis).

Table 1: Key literature relevant to photocell-based (daylight-responsive) lighting control

Main takeaway for this paper	Control approach	Context	Study type	Ref.
Controls often save significant energy, but real savings depend on commissioning and behavior.	Occupancy + daylight + tuning controls	Commercial buildings	Meta-analysis	[2]
Savings potential exists, but sensor placement, zoning, calibration, and acceptance are critical.	Daylight harvesting systems	General (multiple building types)	Literature review	[3]
Savings vary widely by strategy and context; real consumption can differ from theoretical estimates.	Multiple control systems	Offices (EU locations)	Simulation + "real consumption" comparison	[5]
Large savings are possible, but poor commissioning/sensor placement can reduce performance sharply.	Daylight-linked (dimming vs. on/off)	Large atrium spaces	Field monitoring	[6]
Net savings should include parasitic consumption; monitoring is essential to validate performance.	Automated lighting control system	Offices (Italy)	Experimental case study + monitoring	[7]
Behavior can increase use; automatic dimming can still cut consumption if designed correctly.	Occupancy patterns + (tested) dimming strategy	Offices (Korea)	Field monitoring	[8]

3. Methodology

In this study, we utilize a design and evaluate approach for analytical estimation and simulation without physical prototyping, the application of measurement equipment on-site, or experimental monitoring. Two parallel tracks of the workflow are described: (i) conceptual system design (photocell-based control logic and architecture), and (ii) energy-impact evaluation using a standards-alignedcalculation approach and scenario-based modelling. The evaluation is reported as predicted annual lighting electricity use (kWh/year) and predicted savings (%) when shifting from manual operation to automatic photocell-based control.

3.1. Research Design and Scope

The research design is structured as a non-experimental assessment of a proposed household lighting control intervention. The scope is limited to lighting electricity consumption and does not attempt to quantify thermal side-effects (e.g., changes in internal heat gains). Figure 1 **:** Reducing Household Lighting Consumption

The study compares:

- **Baseline case (manual control):** occupants switch lighting on/off with typical behaviour patterns and imperfect timing.
- **Intervention case (photocell-based automatic control):** lighting is automatically switched or dimmed based on available daylight (and optionally constrained by occupancy schedules in the model).

Because prior literature shows that predicted control savings can be sensitive to assumptions and may be overestimated when not validated in real buildings, the modelling strategy incorporates conservative assumptions and a sensitivity analysis rather than a single-point estimate [2, 8].

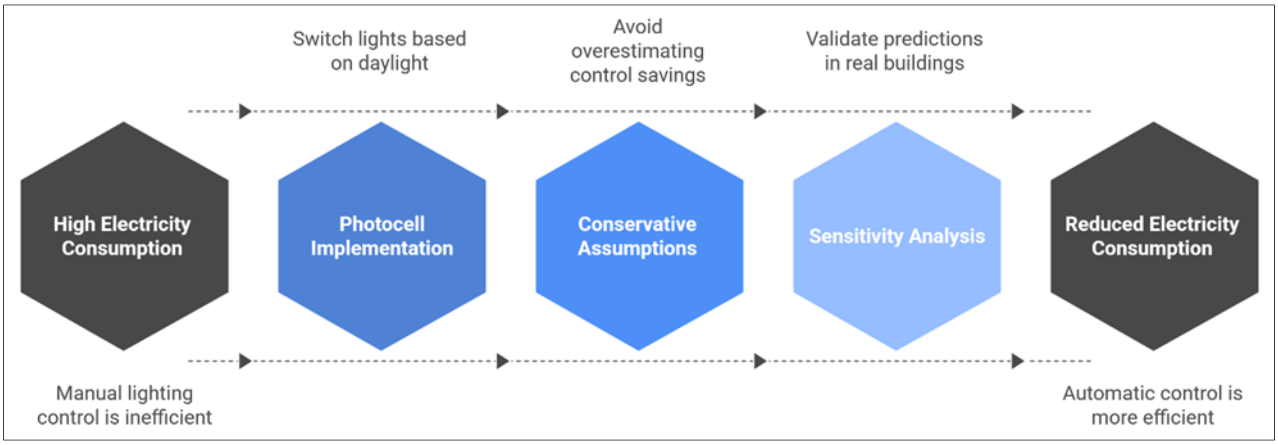

Fig 1 : Reducing Household Lighting Consumption

3.2 Proposed System Architecture

A conceptual photocell-based automatic lighting system is defined at the functional level (no wiring/build instructions are provided). The system is described using modular blocks:

1. **Illuminance sensing unit:** a photocell (e.g., LDR or photodiode module) producing a signal proportional to incident light.
2. **Decision and control logic:** implements a threshold-based rule with **hysteresis** to avoid rapid switching near the setpoint (e.g., "turn ON below E_on" and "turn OFF above E_off" where E_off > E_on).
3. **Switching/dimming actuation:** a switching stage (for ON/OFF control) or a dimming stage (for continuous control), represented in the evaluation as one of two control types:
    - **Manual switching baseline** (no daylight response),
    - **Daylight-linked control** (on/off or continuous dimming) consistent with common daylight harvesting classifications [2, 4, 5].

For safety and real-world deployment, the paper assumes any final implementation would rely on certified components and comply with electrical standards; however, deployment is outside the scope of this non-experimental study, Figure. 2 Photocell-Based Automatic Lighting System Architecture

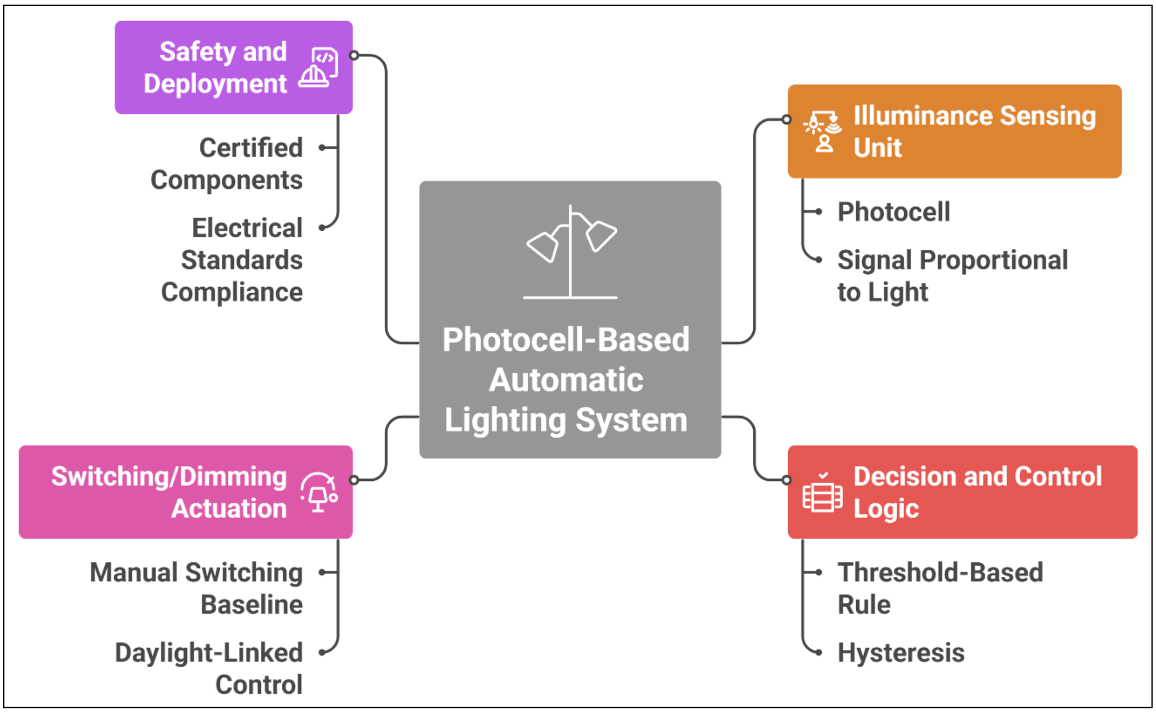

Fig 2: Photocell-Based Automatic Lighting System Architecture

3.3. Energy Modelling Framework (Standards-Aligned Calculation)

To estimate energy consumption without measurements, the study uses a **standardized lighting energy calculation logic** and adapts it to a household context. The core idea follows the EN 15193-1 framework that expresses lighting energy use through installed power and **effective operating time** modified by control-related factors (daylight dependency, occupancy dependency, and control type) [9]–[11].

For each room/zone *i*, annual lighting energy is computed as:

- **Baseline (manual):** Ebase,i=Pi×Huse,i1000E_{base,i} = \dfrac{P_i \times H_{use,i}}{1000}Ebase,i=1000Pi×Huse,i (kWh/year)
- **Automaticdaylight-linked:** Eauto,i=Pi×Huse,i×FD,i×FC,i1000E_{auto,i} = \dfrac{P_i \times H_{use,i} \times F_{D,i} \times F_{C,i}}{1000}Eauto,i=1000Pi×Huse,i×FD,i×FC,i (kWh/year)

Where:

- PiP_iPi = installed lighting power (W) in zone *i*
- Huse,iH_{use,i}Huse,i = annual “would-use” hours under occupancy/activity (h/year)
- FD,iF_{D,i}FD,i = daylight dependency factor (0–1), representing the fraction of time electric lighting is needed given daylight availability and sensor setpoint [9]–[11]
- FC,iF_{C,i}FC,i = control facto**r**, representing how effectively the control strategy reduces energy relative to full-output operation (e.g., switching vs continuous dimming) [9]–[11]

This structure aligns with the standard’s logic (installed power × effective operating hours × control/daylight modifiers), while the study reports kWh/year directly to keep results intuitive for household applications.

3.4. Scenario Definition and Input Parameterization

Because households vary widely, the evaluation uses scenario-based modelling. A “reference household” is represented as a set of typical zones (e.g., living room, kitchen, corridor, outdoor entry), each characterized by lighting power, daylight access category, and usage pattern. Usage patterns are derived as assumption sets guided by the general finding that lighting use follows occupancy and behavioural routines rather than daylight level alone [8].

A minimum of three daylight-access categories are used:

- **High daylight access:** windowed rooms with strong daytime daylight contribution,
- **Moderate daylight access:** partially daylit spaces,
- **Low daylight access:** corridors/inner rooms with limited daylight.

Daylight-linked control performance is represented using either:

- **Simplified standard-factor approach:** assign FD,iF_{D,i}FD,i from daylight-access category and setpoint assumptions, consistent with EN 15193-1 style factors [9]–[11], or
- **Climate-based daylight simulation option (if available):** compute daylight availability and infer FD,iF_{D,i}FD,i from simulated daylight illuminance time series, noting that comparisons between EN 15193-1 calculations and Radiance/DAYSIM-style simulations have been explored in prior work [12]. In this paper, the simplified standard-factor approach is the default, with the simulation option treated as an extension.

Table 2: Key modelling inputs and assumed ranges (used for sensitivity analysis)

Parameter	Symbol	Example range / levels	Purpose
Installed lighting power per zone (W)	PiP_iPi	6–30 W (LED-based room totals)	Captures fixture count and lamp wattage differences
Annual activity/occupancy “would-use” hours	Huse,iH_{use,i}Huse,i	300–2000 h/year (zone dependent)	Represents household routines and occupancy variability [8]
Daylight access category	—	High / Moderate / Low	Drives daylight availability assumptions
Photocell setpoint (switch/dim threshold)	EsetE_{set}Eset	Low / Medium / High (categorical)	Captures commissioning/tuning impact noted in literature [2]
Daylight dependency factor	FD,iF_{D,i}FD,i	0.3–0.9	Reflects how often daylight can replace electric light [9]_[1 1]
Control type factor	FC,iF_{C,i}FC,i	Switching vs continuous dimming	Represents strategy performance differences [4, 5]

3.5 Sensitivity and Uncertainty Analysis

Given the absence of experimental validation, robustness is addressed through a structured **sensitivity analysis**:

1. **One-at-a-time sensitivity:** vary FD,iF_{D,i}FD,i, Huse,iH_{use,i}Huse,i, and EsetE_{set}Eset across plausible ranges while keeping others constant.
2. **Scenario bundles:** define conservative, typical, and optimistic cases:

- **Conservative:** low daylight benefit, higher manual efficiency, imperfect control tuning (higher FD,iF_{D,i}FD,i, lower savings)
- **Typical:** mid-range assumptions
- **Optimistic:** strong daylight access and well-tuned control (lower FD,iF_{D,i}FD,i, higher savings)

The analysis explicitly acknowledges that daylighting-control savings depend strongly on commissioning/tuning, space characteristics, occupant behaviour, and control strategy, consistent with prior findings from monitoring studies and meta-analyses [2, 4, 5, 1 4].

3.6. Benchmarking (Plausibility Checks Against Literature Ranges)

To avoid unrealistic claims, predicted savings are checked against published ranges:

- A large meta-analysis indicates meaningful savings potential from daylighting controls but also warns that simulation-based estimates can overstate real-world savings if assumptions are too optimistic [2].
- Field monitoring and comparative control studies highlight that results vary substantially by space and control type, reinforcing the need to present results as ranges rather than a single number [4, 5].

Therefore, this study reports interval results (min/typical/max) and avoids presenting the outcomes as measured or guaranteed.

3.7. Output Metrics

The study reports:

- Annual lighting energy consumption by zone and total: EbaseE_{base}Ebase, EautoE_{auto}Eauto (kWh/year)
- Predicted energy savings: Savings(%)=Ebase−EautoEbase×100Savings(\%) = \dfrac{E_{base}-E_{auto}}{E_{base}} \times 100Savings(%)=EbaseEbase−Eauto×100
- Sensitivity-ranked drivers (which assumptions most affect savings)

4. System Design and Proposed Implementation

4.1. Design Objectives

The system proposed is a photocell-based automatic lighting controller intended for household applications where lights are often left on unnecessarily during daytime. Our design addresses: (i) energy savings from daylight responsiveness, (ii) operational stability (avoiding rapid ON/OFF cycling), (iii) simplicity and low cost, and (iv) user acceptance through manual override and predictable behavior. Such aims are based on the observed daylight harvesting study-learning that savings can be obtained; however, stability, calibration, and user trust largely govern the degree to which the system works under real use conditions [3, 4, 1 4].

4.2. Functional and Non-Functional Requirements

Functional requirements

1. Automatic response to ambient illumination (turning lights ON when daylight is insufficient and OFF/reducing output when daylight is sufficient).
2. Anti-flicker behavior using **hysteresis** and **time delay**.
3. Manual override (AUTO/MANUAL) to accommodate user preference and unusual conditions.
4. Basic fault tolerance (predictable state under sensor error or unstable readings).

Non-functional requirements

- Low implementation complexity suitable for households.
- Minimal standby (auxiliary) power, since parasitic consumption can reduce net savings in practice [5, 7].
- Clear and consistent behavior to improve acceptance and reduce “disablement” over time [14].

4.3. System Architecture

The architecture is defined at a **conceptual level** (sufficient for academic reproducibility while avoiding installation-specific electrical details). It consists of four main blocks:

1. **Illumination sensing block :** A photocell/photosensor produces a signal proportional to ambient illumination. The purpose of the sensor is to reflect the lighting environment of the tested region (task space or representational ambient environment). Placement and field of view of the photosensor play a significant role with respect to stable and performant control and are thus considered as a design hypothesis, although the condition in each study is treated as a sensitivity factor and not as a static “ideal” event [4, 13].
2. **Signal processing and conditioning**: Sensor readings are filtered to remove short transient fluctuations (e.g.,

short shadows) through simple smoothing (e.g., moving average) or persistence logic. This minimizes nuisance switching and enhances stability, which is a common theme that appears in the daylight-linked control practice guidance [3, 14].

3. **Decision and control logic:** The approach for control is threshold-based, supported by hysteresis and time delay. The controller is implementable either through a microcontroller (MCU) or a dedicated analog comparator/control module; therefore, the research is implementation-agnostic and focuses only on the functional behavior.
4. **Actuation interface :** The output drives the lighting load through a switching interface (ON/OFF control) or a dimming interface (continuous control). Since published evidence shows that dimming-based daylight control can outperform pure switching in many contexts (but requires more capable drivers and commissioning), both actuation types are considered in the design description, while the evaluation framework (Section 3) captures their effect through control factors.

As found in Figure 3 Block diagram of the proposed photocell-based lighting control system.

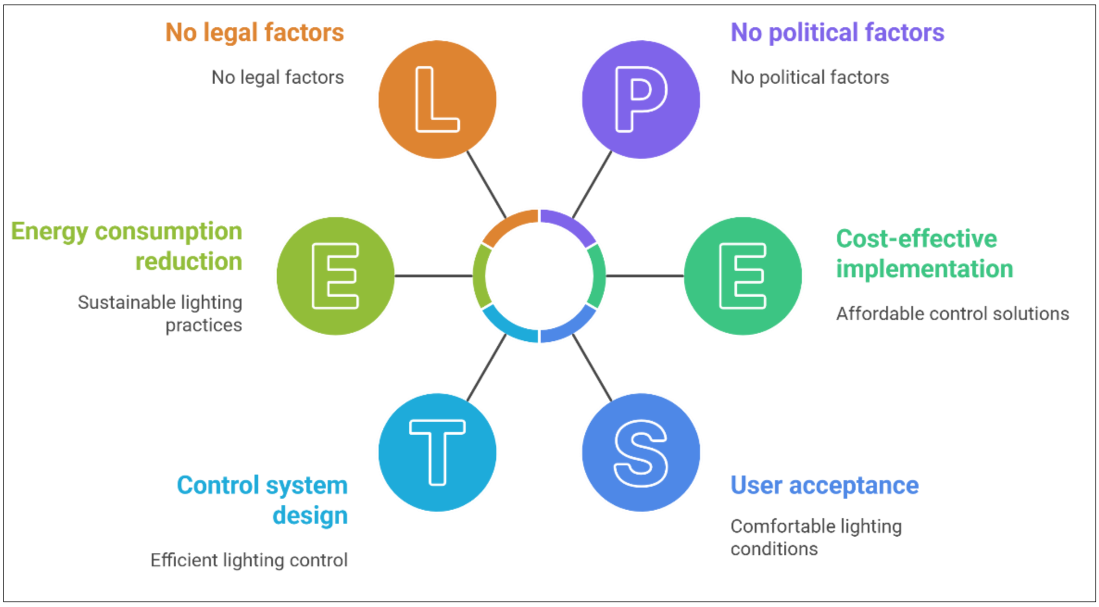

Fig 3: Lighting Control System Architecture

4.4. Sensing Strategy: Open-Loop vs Closed-Loop Considerations

The daylight control literature recognizes two canonical sensing architectures: open-loop (sensor primarily measures daylight contribution) and closed-loop (sensor measures a combination of daylight and electric light, forming feedback) [4]. For low-cost household applications, an open-loop approach is often conceptually simpler and may reduce undesirable self-feedback effects; however, it can be more sensitive to placement and daylight distribution. Closed-loop strategies can better regulate maintained illuminance but may require careful sensor positioning, calibration, and reflective-surface considerations to avoid instability [4, 13]. In this paper, the proposed household concept is presented in a way that enables either architecture, but makes explicit placement and calibration assumptions as important determinants of predicted performance.

4.5. Control Logic Design (Threshold + Hysteresis + Time Delay)

A common cause of poor user acceptance in automatic lighting is "chattering" near the control threshold when daylight fluctuates. To mitigate this, the control logic includes:

1. **Two thresholds (hysteresis band):**
   - EONE_{ON}EON: illumination level below which lighting is allowed/required to turn ON
   - EOFFE_{OFF}EOFF: illumination level above which lighting is turned OFF (or dimmed down), with EOFF>EONE_{OFF} > E_{ON}EOFF>EON
2. **Persistence time delay (TdelayT_{delay}Tdelay)** Illumination must remain above/below the corresponding threshold continuously for TdelayT_{delay}Tdelay seconds before a state change occurs. This prevents switching due to momentary changes such as passing clouds or brief occlusions.
3. **Optional smoothing** A simple moving average or median filter can be applied to the sensor signal, which has been discussed as a practical technique in photosensor-based control modelling and evaluation [13].

4.6. Parameter Definition and Commissioning (Conceptual)

Because this paper does not include physical commissioning, parameter selection is treated systematically and transparently. The main adjustable parameters are:

Table 3.: Control parameters and their role (conceptual commissioning guide)

Parameter	Symbol	Role in the controller	Expected impact on savings and comfort
ON threshold	EONE_{ON}EON	Turns lights ON when ambient illumination is too low	Higher EONE_{ON}EON increases comfort but may reduce savings
OFF threshold	EOFFE_{OFF}EOFF	Turns lights OFF/reduces output when daylight is sufficient	Lower EOFFE_{OFF}EOFF may increase savings but risks under-lighting
Hysteresis width	ΔE=EOFF−EON\Delta E = E_{OFF}-E_{ON}ΔE=EOFF−EON	Prevents rapid cycling around the setpoint	Wider band improves stability but may reduce responsiveness
Time delay	TdelayT_{delay}Tdelay	Requires persistence before switching	Longer delay improves stability but may reduce savings
Control mode	—	Switching vs dimming	Dimming can yield higher savings but needs compatible drivers and tuning [4, 5]
Manual override	—	Allows user to enforce preferred state	Improves acceptance; may reduce savings if overused [1 4]

These parameters are treated as modelling inputs through FDF_DFD and control factors in Section 3, which also aligns with prior evidence that commissioning/tuning can materially change outcomes [2, 4].

4.7. Residential Deployment Considerations (Target Zones)

The controller used here is best for the household area as (i) daylight is available for some of the day, (ii) the lights are typically left on due to habit or convenience. Living rooms with windows for example, kitchens with daylight spillover, entrance or corridor-adjacent areas to receive daylight, etc. On the other hand, the benefit of daylight control would be small in rooms usually used at night, or rooms with limited exposure to daylight as they are usually low HdayH_{day}Hday and FDF_DFD approaches 1.0 (represented in the scenario model) [8]. This aligns with the overall finding that occupant routines can dominate lighting energy outcomes [8] and that control strategies need to correspond with the usage profile in order to be effectively applied [2, 14].

4.8. Scope and Safety Statement

This paper describes a conceptual system design and non-experimental analysis. It doesn't give installation instructions or mains wiring details. Any actual implementation in the homes should be based on certified components and done properly per the correct electrical safety codes. This scope preference adheres to the intent of the study to generate a publishable, reproducible design and modelling framework which can be tested in future work as data is available.

5. Results

5.1. Reference Case Definition

Following the methodology in Section 3, a reference household lighting set is represented as a single aggregated "controlled zone group" (e.g., living area + corridor + kitchen) with:

- Installed lighting power: P_inst = 120 W
- Annual "would-use" hours (activity/occupancy driven): H_use = 1825 h/year (≈ 5 h/day)
- Baseline (manual) annual energy:

  E_base = (P_inst × H_use) / 1000 = (120 × 1825) / 1000 = 219.0 kWh/year

To represent daylight-related reduction under automatic photocell control, the model splits annual use into daytime and nighttime components and applies a daylight dependency factor F_D during daytime (Section 3; EN 15193-1 logic) [9]–[11]. The evaluated scenarios reflect the well-established variability of daylight-control outcomes due to tuning/commissioning and user behavior [2, 4, 5, 8].

5.2. Predicted Energy Use Under Photocell Control (Three Scenarios)

The controller is assumed to reduce daytime lighting energy according to F_D, while nighttime use remains unchanged (since daylight is negligible). Table 5 summarizes the resulting annual energy and predicted savings.

Table 5: Predicted annual lighting energy and savings

Scenario	Daytime share of use	H_day (h/y)	H_night (h/y)	F_D	E_base (kWh/y)	E_auto (kWh/y)	Savings (kWh/y)	Savings (%)
Conservative	30%	548	1277	0.90	219.0	212.4	6.6	3.0%
Typical	45%	821	1004	0.75	219.0	194.4	24.6	11.2%
Optimistic	60%	1095	730	0.60	219.0	166.4	52.6	24.0%

Interpretation.

- The conservative case represents limited daylight benefit and/or imperfect tuning (high F_D), resulting in modest savings.
- The typical case reflects moderate daylight availability and reasonable setpoint selection, producing a mid-range reduction.
- The optimistic case represents strong daylight access with effective tuning and stable operation, yielding the highest predicted savings.

This range-based reporting is consistent with prior evidence that daylight-control savings are highly context-dependent and that modelling-only estimates should be interpreted conservatively [2, 4].

5.3. Sensitivity Analysis (Key Drivers of Savings)

From the analytical model, the **relative savings** are governed by a simple relationship:

Savings (%) = (Daytime share) × (1 − F_D) × 100

This clarifies which assumptions matter most. Table 6 provides a compact sensitivity map showing predicted savings (%) for common combinations of daytime use share and F_D

Table 6: Sensitivity of predicted savings (%) to daytime share and F_D

Daytime share → / F_D ↓	30%	45%	60%
0.90	3.0%	4.5%	6.0%
0.75	7.5%	11.25%	15.0%
0.60	12.0%	18.0%	24.0%

Ranking of influence

1. **Daytime share of lighting use** (behavior + schedules): if most usage occurs at night, daylight control cannot save much, regardless of design. This aligns with behavioral findings that lighting use often follows occupancy/time-of-day routines rather than daylight level alone [8].
2. **F_D (daylight dependency factor)** (daylight access + tuning/commissioning): lower F_D indicates that daylight more effectively displaces electric light. The strong role of tuning and system setup is consistent with monitoring-based evidence and design guidance [4, 13, 14].
3. **Installed power (P_inst)** scales savings linearly: higher installed power yields larger kWh savings for the same percentage reduction (Section 3).

5.4. Plausibility Check Against Published Evidence

A meta-analysis of lighting control studies indicates typical daylighting savings in commercial settings on the order of ~28%, but it cautions that modelling and simulation methods may overstate daylighting savings if real commissioning and operational constraints are not represented [2]. Monitoring studies also show wide variability, with outcomes strongly affected by control type, commissioning quality, and occupant behavior [4].

Accordingly, the present results are reported as bounded scenarios (3–24%) rather than a single value and are framed as predicted (not measured). The optimistic scenario approaches the magnitude reported in aggregated literature, while the typical and conservative cases reflect the practical reality that many households have limited daytime lighting use or limited daylight penetration in key zones [8]. In other words, the predicted savings are most plausible for daylit common areas with significant daytime occupancy and well-chosen thresholds, and less plausible for predominantly night-used zones.

5.5. Summary of Key Findings

1. For the reference household-zone case (120 W, 1825 h/year), the baseline annual lighting electricity is 219.0 kWh/year.
2. Under photocell-based daylight-responsive control, predicted savings span 3.0% to 24.0% depending on daylight availability, control tuning (F_D), and daytime usage share.
3. The dominant determinant of savings is the combination of (i) how much lighting is used during daylight hours and (ii) how strongly daylight can reduce electric lighting need (F_D), consistent with prior behavioral and monitoring evidence [4, 8].

6. Discussion

6.1. Interpretation of the Predicted Savings

Scenario-based results reveal that a photocell-based daylight-responsive controller can decrease household lighting electricity consumption mostly due to the elimination of avoidable daytime lighting operation. The estimated savings range (3.0–24.0%) is dictated by two drivers: (i) the proportion of lighting use that occurs during daylight hours (behavior/schedules) and (ii) the daylight dependency factor FDF_DFD, which measures how well daylight replaces electric lighting across the selected setpoint and sensing conditions (Section 5). This is consistent with monitoring evidence that lighting use is often a function of time-of-day routines and occupant habits and not simply daylight, so if most lighting use is night-time or users habitually override automation [8], control benefits would be limited.

6.2. Consistency with Prior Literature

One primary lesson from meta-evidence results is that lighting controls can yield considerable savings [2], but their real-world impacts differ significantly based on commissioning quality, control strategy, and operational context. Monitoring-based data also prove that differences in daylight control configuration for otherwise similar spaces yield widely different annual savings, underlining the importance of sensing strategy and tuning [4]. Hence, reporting savings as a bounded range (conservative/typical/optimistic) is more credible than a single-point assertion. The current scenario envelope is deliberately conservative compared with some commercial-building daylighting results, reflecting that many household zones have lower daytime lighting use shares and more heterogeneous daylight access, which can reduce the achievable benefit [8].

6.3. Implications for System Design

User acceptance is key to residential automation: if occupants feel that the system is nuisance switching or behaving inconsistently, they may simply disable the system, eliminating savings. The design methodologies proposed as hysteresis and time delay alleviate this risk by minimizing switching around threshold conditions. This is consistent with larger literature discussing photosensor control performance and the observation that real-world results will depend greatly on good tuning as well as stable control behaviour [4, 13, 14]. Further, parasitic consumption of sensors/controllers can reduce net savings; thus minimizing standby power is important in small residential lighting loads, where absolute kWh savings could be modest in conservative scenarios [5, 7].

6.4. Practical Applicability

The model implies that the system is most attractive in:

- **Daylit common zones** (living rooms, kitchens with windows) where lights are frequently left on during daytime;
- **Households with significant daytime occupancy**, where the daytime share of use is higher.

By contrast, zones used mostly at night (bedrooms used after sunset, exterior lighting at night) naturally offer less daylight-control opportunity because the daylight-related term contributes little to annual energy use (Table 6). This reinforces the importance of selecting appropriate target zones when evaluating or deploying daylight-linked controls [2, 8].

7. Cost and Payback

Because this study is non-experimental, cost analysis is presented as an indicative framework rather than a market-verified bill of materials. The payback period depends on three inputs:

1. installed system cost CsysC_{sys}Csys,
2. annual electricity savings ΔE\Delta EΔE (kWh/year),
3. electricity tariff cec_ece (currency/kWh).

7.1. Cost Components

Typical cost elements for a low-cost household controller include:

- photosensor module (photocell + conditioning),
- controller/logic module,
- output interface appropriate to the lighting driver type,
- enclosure and low-voltage supply,
- installation labor (if applicable).

To remain consistent with safety and scope, this paper does not provide installation instructions or component-level wiring details; cost should be interpreted as a conceptual planning metric.

7.2. Payback Formulation

Annual monetary savings:

Smoney=ΔE×ceS_{money} = \Delta E \times c_eSmoney =ΔE×ce

Simple payback period:

Payback=CsysΔE×cePayback = \frac{C_{sys}}{\Delta E \times c_e}Payback=ΔE×ceCsys

7.3. Example Payback Sensitivity

Using the **typical** predicted savings from Table 5 (ΔE=24.6\Delta E = 24.6ΔE=24.6 kWh/year), Table 7 illustrates how payback changes with tariff and system cost.

Table 7: Simple payback sensitivity (typical case, ΔE=24.6\Delta E = 24.6ΔE=24.6 kWh/year)

CsysC_{sys}Csys	ce=0.05c_e = 0.05ce=0.05 /kWh	ce=0.10c_e = 0.10ce=0.10 /kWh	ce=0.20c_e = 0.20ce=0.20 /kWh
10	8.1 years	4.1 years	2.0 years
20	16.3 years	8.1 years	4.1 years
30	24.4 years	12.2 years	6.1 years

The sensitivity of the system to this feature illustrates a key practical point: if the savings are modest (as in conservative conditions) and the electricity tariffs are low, payback may become long unless system cost and standby consumption are kept to a minimum. Conversely, in better daylight contexts or with higher tariffs the case becomes more economic.

7.4. Interpreting Economic Results with Care

The literature emphasizes that realized savings can be lower than predicted when commissioning, placement, and behavior effects are not captured in modelling [2, 4]. Therefore, payback should be interpreted as indicative and ideally recalculated using household-specific parameters (daytime share, daylight access, lamp wattage, tariff).

8. Limitations and Future Work

8.1. Limitations

1. **No field measurements:** All results are scenario-based predictions; no real household monitoring was performed.
2. **Aggregated modelling:** The reference case aggregates several household zones into one representative group; individual room differences (window geometry, shading, orientation) are simplified into FDF_DFD.
3. **Commissioning not validated:** Threshold selection, sensor placement, and tuning are treated as assumptions, yet they can materially affect outcomes [4, 13, 14].
4. **Parasitic power not explicitly modelled:** Standby consumption can reduce net savings, especially under conservative savings conditions [5, 7].
5. **Comfort metrics not quantified:** Visual comfort and perceived adequacy of illumination were not measured; these factors can influence acceptance and long-term use [1 4].

8.2. Future Work

Future research should strengthen validity by:

- **Short-term field trials** (before/after monitoring) in multiple homes and seasons to calibrate FDF_DFD and validate stability;
- **Room-level modelling** with daylight simulation (e.g., Radiance/DAYSIM) to better estimate daylight availability, as explored in comparisons with EN 15193-1 methods [1 2];
- **Hybrid sensing** (daylight + occupancy) to reduce waste in intermittently used rooms, consistent with the broader evidence base on lighting controls [2, 8];
- **User acceptance evaluation** to quantify override frequency and perceived comfort, which strongly influences real-world persistence of savings [14].

9. Conclusion

A photocell-based automatic lighting control concept was presented for households and its energy-saving potential was assessed through a standards-aligned, scenario-based analytical framework without physical experiments. It can be concluded from the results that daylight-aware automatic control can reduce avoidable daytime lighting operation, with predicted savings ranging from 3.0% to 24.0% under conservative-to-optimistic assumptions for a representative household zone group. Based on sensitivity analysis, the daytime share of lighting use is revealed to be the dominant driver alongside daylight dependency factor FDF_DFD, indicating the key role of occupant routines, daylight access, and commissioning/tuning quality in previous works [2, 4, 8]. Although these results lend empirical support to the feasibility of low-cost, daylight-linked household control technology, this research emphasises the importance of real-world validation and user-centered deployment considerations to translate projected savings into real, sustainable outcomes [4, 14].

10. References

1. Rosenberg E. Calculation method for electricity end-use for residential lighting. Energy. 2014;66:295-304. doi:10.1016/j.energy.2013.12.049
2. Williams A, Atkinson B, Garbesi K, Rubinstein F, Page E. A meta-analysis of energy savings from lighting controls in commercial buildings. Berkeley (CA): Lawrence Berkeley National Laboratory; 2011 Sep.
3. Gentile N, Dubois MC, Laike T. Daylight harvesting control systems design recommendations based on a literature review. In: 2015 IEEE 15th International Conference on Environment and Electrical Engineering (EEEIC); 2015 Jun 10-13; Rome, Italy. Piscataway (NJ): IEEE; 2015. p. 632-7. doi:10.1109/EEEIC.2015.7165237
4. Delvaeye R, Ryckaert W, Stroobant L, Hanselaer P, Klein R, Breesch H. Analysis of energy savings of three daylight control systems in a school building by means of monitoring. Energy Build. 2016;127:969-79. doi:10.1016/j.enbuild.2016.06.033
5. Roisin B, Bodart M, Deneyer A, D'Herdt P. Lighting energy savings in offices using different control systems 10.and their real consumption. Energy Build. 2008;40(4):514-23. doi:10.1016/j.enbuild.2007.04.006
6. Atif MR, Galasiu AD. Energy performance of daylight-linked automatic lighting control systems in large atrium spaces: report on two field-monitored case studies. Energy Build. 2003;35(5):441-61. doi:10.1016/S0378-7788(02)00142-1
7. Aghemo C, Blaso L, Pellegrino A. Building automation and control systems: a case study to evaluate the energy and environmental performances of a lighting control system in offices. Autom Constr. 2014;43:10-22. doi:10.1016/j.autcon.2014.02.015
8. Yun GY, Kim H, Kim JT. Effects of occupancy and lighting use patterns on lighting energy consumption. Energy Build. 2012;46:152-8. doi:10.1016/j.enbuild.2011.10.034
9. British Standards Institution. BS EN 15193-1:2017+A1:2021 Energy performance of buildings. Energy requirements for lighting. Specifications (Module M9). London: BSI; 2021.
10. Aghemo C, Blaso L, Fumagalli S, Lo Verso VRM, Pellegrino A. The new prEN 15193-1 to calculate the energy requirements for lighting in buildings: comparison to the previous standard and sensitivity analysis on the new influencing factors. Energy Procedia. 2016;101:232-9. doi:10.1016/j.egypro.2016.11.030
11. CEN. CEN/TR 15193-2:2017 Energy performance of buildings. Energy requirements for lighting. Part 2: explanation and justification of EN 15193-1 (Module M9). Brussels: European Committee for Standardization; 2017.
12. Akimov L, De Michele G, Filippi Oberegger U, Badenko V, Mainini AG. Evaluation of EN15193-1 on energy requirements for artificial lighting against Radiance-based DAYSIM. J Build Eng. 2021;40:102698. doi:10.1016/j.jobe.2021.102698
13. Ehrlich C, Papamichael K, Lai J, Revzan K. A method for simulating the performance of photosensor-based lighting controls. Energy Build. 2002;34(9):883-9. doi:10.1016/S0378-7788(02)00064-6
14. Gentile N, Osterhaus W, editors. Literature review—energy saving potential of user-centred integrated lighting solutions (IEA SHC Task 61 / EBC Annex 77). International Energy Agency Solar Heating and Cooling Programme; 2021. doi:10.18777/ieashc-task61-2021-00132021-0013doi:10.18777/ieashc-task61-2021-0013

How to Cite This Article

Jawad A, Abdulzahra RR, Khudair NAR, Sameer MM, Munshid RA. Design and simulation-based evaluation of a photocell based automatic lighting control system for household energy saving. Int J Multidiscip Compr. 2026;5(1):1–10. doi:10.54660/IJMCR.2026.5.1.01-10.

Creative Commons (CC) License