Final Validation Report

EcoBright Motion Sensing LED Validation Project

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1 Executive Summary

This report presents the final validation study of EcoBright's motion sensing LED lighting system conducted at the ELIXIR Laboratory at Toronto Metropolitan University. The purpose of the project was to evaluate the operational performance of the sensing and dimming system and to assess its potential to reduce lighting energy consumption and carbon impact in commercial applications.

Testing was carried out under controlled laboratory conditions using representative occupancy scenarios designed to simulate different building environments, including indoor spaces and parking garage applications. A repeatable actuator based test system was developed to generate consistent stimulus events for the sensing hardware, while continuous logging was used to capture fixture response, dimming behaviour, and operating state over time. The data was collected in a compressed state to simulate multiple days of movement within a 24 hour period. The Shopping and Fitness centre scenarios implement an 8/8/8 duty cycle decompression algorithm (8 hours on, 8 hours dimmed, 8 hours off), to simulate the average behaviour of these usual environments. The rest of the scenarios calculate savings 1:1 from the raw data to provide a worst case baseline and guarantee saving values.

Overall, the results showed that the system responded reliably to simulated occupancy activity, followed the configured control behaviour, and demonstrated clear potential for reducing unnecessary lighting operation when compared to an always on baseline. The analysis supports the use of occupancy based lighting control as an effective strategy for improving energy efficiency, lowering operating costs, and reducing environmental impact across a range of commercial settings.

1.1 Key Outcomes

- **Detection performance:** The sensing system responded reliably under the tested occupancy scenarios.
- **Control behaviour:** The lighting system followed the intended dimming and timing behaviour under controlled conditions.
- **Data collection:** Logging was successfully used to capture system operation and support the final energy analysis.
- **Overall result:** The validated system demonstrated strong potential for reducing unnecessary lighting energy use in real building applications.

2 Introduction

Lighting systems in commercial and institutional facilities often operate for extended periods regardless of whether a space is occupied. This leads to unnecessary energy consumption, increased operating costs, and avoidable greenhouse gas emissions. Occupancy sensing lighting systems address this inefficiency by allowing light fixtures to respond dynamically to the presence or absence of occupants rather than remaining continuously active.

EcoBright has developed a motion sensing LED lighting system designed to reduce energy waste by automatically adjusting fixture output based on detected activity within the environment. All lighting behaviour is configurable through the EcoBright control application, allowing the user to define parameters such as trigger brightness, standby dimming level, hold time, and shutoff delay. Because these settings are user defined, the fixture can transition between any selected brightness level depending on occupancy conditions, meaning the system may increase or decrease brightness as required. In most practical applications, lighting is typically configured to operate at a higher brightness level when motion is detected and transition to a lower standby brightness level or turn off after a period of inactivity. The system provides full control over these parameters so that lighting behaviour can be tailored to different building types, occupancy patterns, and energy saving requirements.

The purpose of this project was to experimentally validate the performance and energy savings potential of this lighting system under controlled laboratory conditions. Testing was conducted at the ELIXIR Laboratory at Toronto Metropolitan University using a EcoBright 2×2 LED fixture equipped with an occupancy sensing control module.

To produce consistent and repeatable occupancy events, a controlled actuation system was developed to simulate the infrared emission of a moving human occupant. Passive infrared (PIR) sensors detect changes in infrared radiation emitted by warm objects such as the human body. To replicate this behaviour, a heating element was mounted to an anodized black aluminum plate to provide a stable thermal emission surface.

The heated plate was attached to a servo driven actuator which moved the infrared source through the sensor's field of view. This allowed motion and thermal radiation changes to be reproduced in a controlled and repeatable manner, enabling realistic occupancy events to be simulated without requiring human participants.

The primary sensing configuration evaluated during testing used a passive infrared (PIR) motion sensor commonly applied in indoor environments such as classrooms, retail stores, warehouses, and fitness facilities.

The study also considered an underground parking garage scenario. Parking facilities experience long periods of inactivity interrupted by occasional vehicle movement. Because of the larger sensing area required in these environments, microwave motion sensors are commonly used instead of passive infrared sensors. For this scenario, a dedicated parking garage panel equipped with a microwave motion sensor was used rather than the 2×2 panel fixture evaluated in the indoor tests. To maintain consistent experimental conditions, the same servo driven actuator and heated target were used to generate repeatable motion events for this configuration.

Occupancy sensing lighting controls can significantly reduce lighting energy consumption by automatically dimming or turning lights off when spaces are unoccupied. Lighting accounts for approximately 13–13.5% of total energy use in commercial and institutional buildings in Canada, highlighting the importance of lighting control strategies for energy efficiency improvements [7]. Energy efficiency programs report that occupancy sensors can reduce lighting energy costs by up to approximately 40% depending on the building type and usage patterns [9]. These strategies are particularly beneficial in spaces such as warehouses, corridors, and parking facilities where lighting may otherwise operate continuously [8].

Based on these application scenarios, the objectives of this validation study were to evaluate sensor detection performance, observe fixture dimming behaviour and hold times, analyze system response under different occupancy patterns, and estimate potential energy savings compared to a conventional always-on lighting configuration.

3 System Overview & Hardware Set up

3.1 Test System Materials

Item	**Model / Version**	**Notes**
LED Fixture	P-347-TCP	Povided by EcoBright
PIR Sensor	ANT 1P 4T	Povided by EcoBright
Microwave Sensor		Provided by EcoBright
Stimulus Module	Beam, heat source, servo	3D printed PLA actuator with PTC and black aluminum heating element
Controller	ESP32 WROVER	
Resistor	4.7k Ω	
Resistor	10k Ω	
Resistor	1k Ω	
Resistor	220 Ω	
Resistor(s)	9x 10 Ω	
Resistor(s)	3x 100 Ω	
Power	5 V supply	Supplies 5V 6A DC
Power	5 V supply	Arduino PSU
Power	120 V supply	12(AWG) wall plug

Table 1: System under test and version tracking

3.2 Bill of Materials

Item	Quantity	Unit Price	Total Invoice
25kg Servo	1	$43.99	$49.71
Arduino PSU	1	$15.99	$18.07
Heating Element	1	$12.99	$14.68
Clamp	1	$17.99	$20.33
ESP32 Kit	1	$49.95	$51.92
Screw Kit	1	$34.97	$39.52
Wall Adapter	1	$35.57	$40.19
Sensor Adapters	4	$8.69	$8.69
Anodized Aluminum	1	$22.45	$22.37
Cork	1	$14.50	$15.50
Thermal Paste	1	$6.37	$8.24
Bracket	1	$21.89	$24.74
Ruler	1	$9.99	$11.29
5V 6A Adapter	1	$24.21	$24.21
Glue Stick	1	$2.49	$3.11
PLA Filament	1	$20.69	$23.68
Blade	1	$1.00	$12.41
Drill Bits	1	$29.98	$79.05
Drill	1	$69.99	$79.71
Hack Saw	1	$9.98	$0.00
Sockets	1	$39.98	$0.00
Wi-Fi Adapter	1	$14.99	$16.94
Glue Gun/Sticks	1	$15.32	$15.32
Webcam	1	$29.99	$33.89
DP to HDMI Cable	1	$56.49	$56.49
		Subtotal (Raw):	$610.45
		Total (After Tax):	**$670.06**

Table 2: System Bill of Materials (BOM) and Final Costs

4 Test Environment and Setup

4.1 Physical Layout

All experiments were conducted in a controlled test environment constructed beneath a table structure at the ELIXIR Laboratory at Toronto Metropolitan University. The testing region was enclosed using cardboard panels in order to isolate the sensor from external movement and environmental disturbances.

The PIR motion sensor was mounted independently to the underside of the table, facing downward toward the floor. This positioning was chosen to replicate a typical real world installation in which a motion sensor would be mounted to a ceiling or lighting fixture and directed downward toward the occupied space. Mounting the sensor in this orientation ensured that the sensing geometry closely resembled how the system would operate in an actual building environment.

For the parking garage evaluation, the PIR sensor was removed and replaced with a microwave motion sensor while maintaining the same mounting position and overall bench layout. This allowed the parking garage configuration to be tested under the same geometric and environmental conditions as the indoor PIR setup. By keeping the actuator system, heated target, and sensor location consistent, differences in system response could be attributed primarily to the sensing configuration rather than to changes in the physical test environment.

The PIR sensor was powered through a connection to the EcoBright 2×2 LED panel. The LED panel itself was placed vertically against the left wall of the test environment, facing toward the center of the setup as shown in Figure 2. The LED panel served as the power source for the sensor during testing and was supplied power through a heavy duty Iron Forge Cable 12 gauge power cord connected to a standard wall outlet. For the parking garage tests, the same electrical and physical configuration was maintained using the dedicated parking garage panel equipped with the microwave motion sensor, ensuring that both sensing configurations were evaluated under consistent experimental conditions.

To simulate human presence within the detection region, a servo driven actuator system was mounted to the front leg of the table using a clamp fixture. The servo motor drove a horizontal actuator beam that extended into the test area. At the end of this beam, a controlled infrared radiation source was installed consisting of a heating element mounted to an anodized black aluminum plate. The heated plate acted as a thermal emitter designed to replicate the infrared radiation signature of a human body and to generate detectable motion events for both indoor occupancy scenarios and vehicle movement conditions evaluated in the parking garage configuration.

During testing, the servo moved the heated plate through the sensor's field of view, producing both motion and thermal radiation changes detectable by the PIR sensor. This allowed realistic occupancy events to be reproduced in a controlled and repeatable manner without requiring human participants.

A monitoring camera was positioned on the floor at an angle that captured the entire experimental setup. This camera allowed actuator movement, sensor responses, and potential false triggers to be visually verified throughout the experiments.

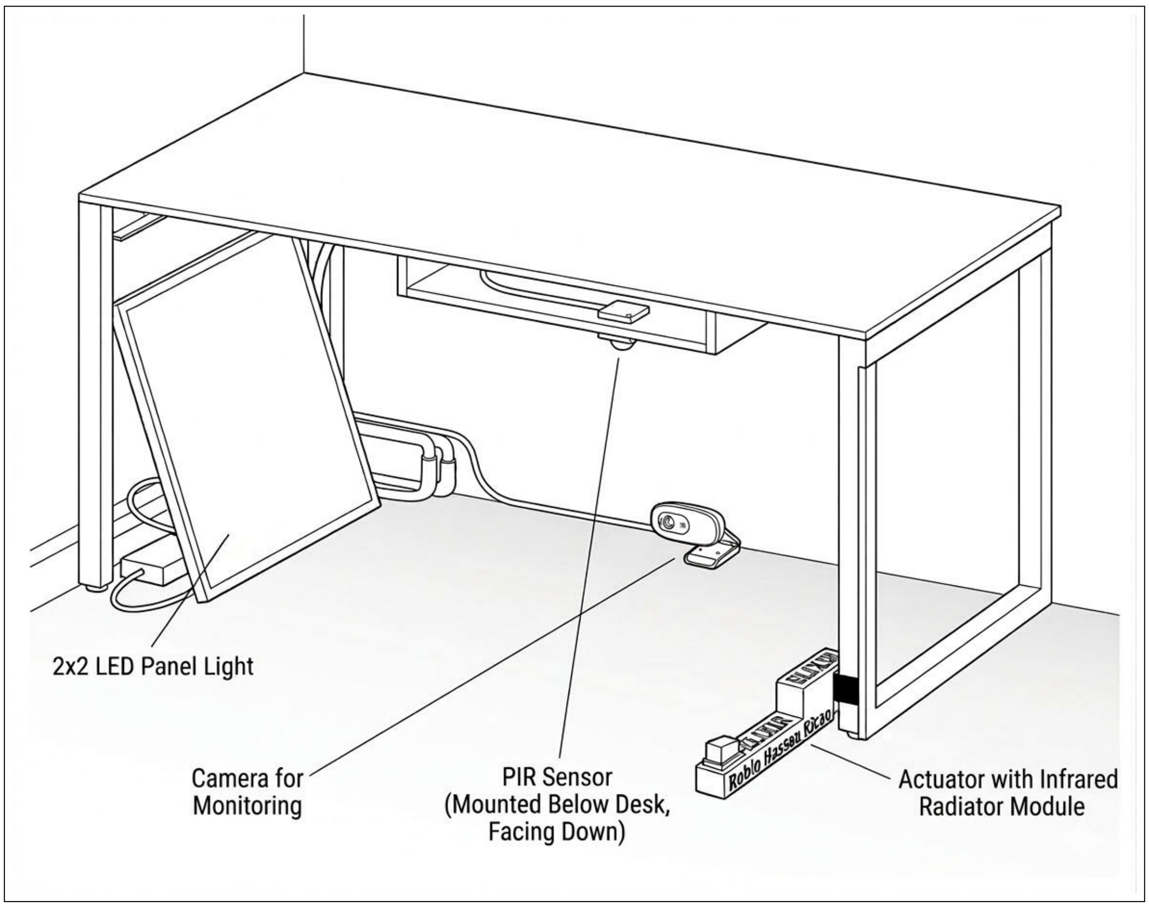

Figure 1: Schematic layout of the experimental test setup showing the sensor mounting position, LED panel placement, and actuator based infrared radiator used to simulate occupancy events. The isolation panels used during testing are not shown for visibility

Figure 2: Photograph of the physical experimental setup used during testing, including the sensor mounting position, LED panel, and actuator based stimulus system. The isolation panels used during testing are not shown for visibility.

4.2 Electrical Setup

The electrical control system consists of the ESP32 WROVER-E microcontroller, PTC heating element, PIR & Microwave sensor signals, the servo signal, and the servo control path. The EcoBright LED fixture was powered directly via a standard 120V AC line. The control system circuit was powered by an isolated 5V 6A DC supply and a 5V arduino power supply. A shared common ground was established across all low-voltage DC components to prevent floating signals and maintain reliable readings. The physical simulation was controlled by a PWM signal sent from the ESP32 to the servo motor (Pin 13). The output voltage from the sensor activation was routed directly to a digital input on the microcontroller through a voltage divider (4.7k and 10k resistor), to drop the signal down to ∼2.4V. To track the panels active state, the ESP32 program was calibrated with a 2.5V reference that represents 100% brightness. This allowed the test bench to continuously measure and log the precise dimming ratio of the fixture as it transitions between active, dimmed, and off states.

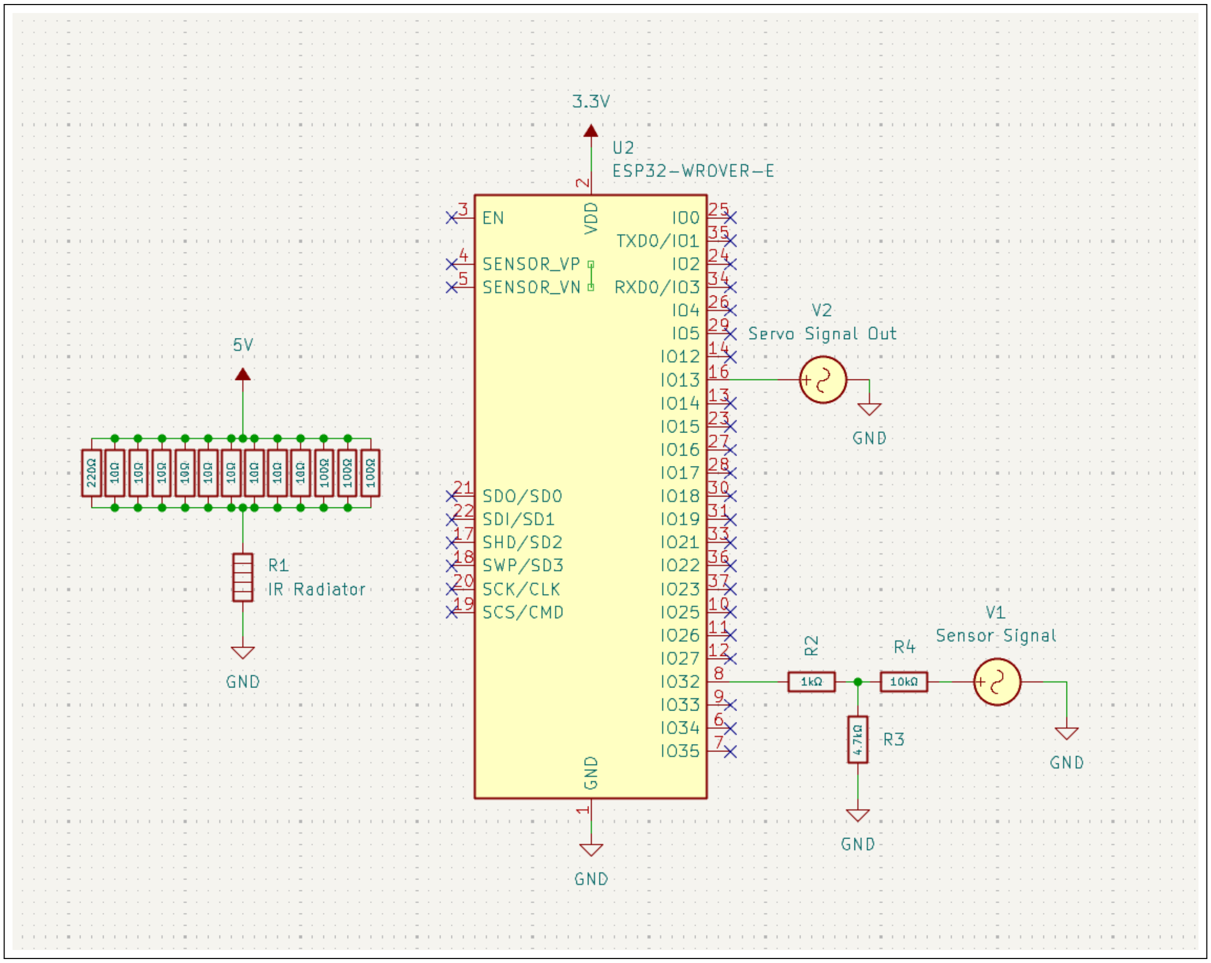

Figure 3: Electronic Diagram

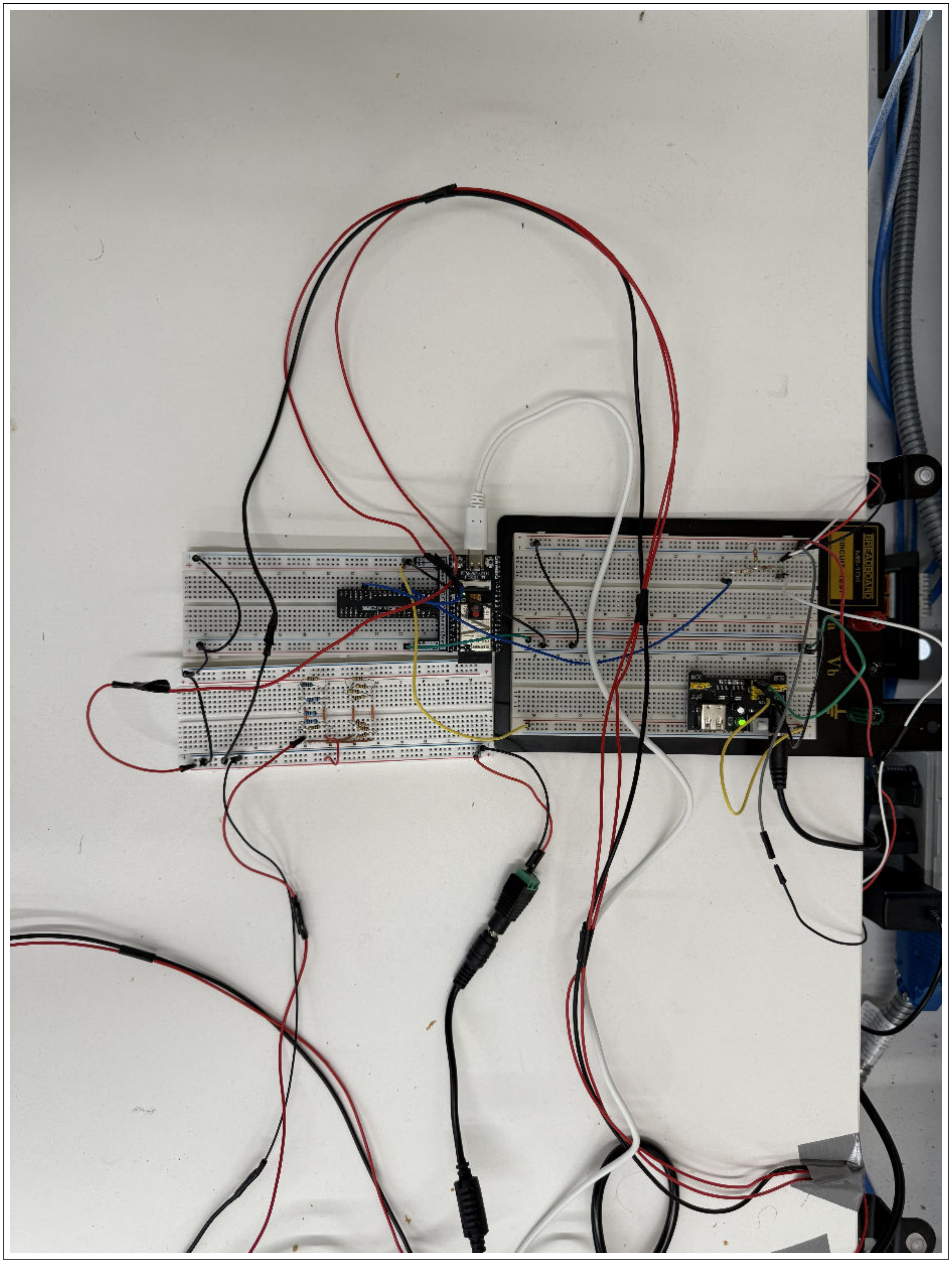

Figure 4: Physical Electronic Setup

5 Test Methodology

5.1 Overview

The primary objective of this testing methodology is to accurately simulate real-world occupancy scenarios and quantify the energy savings generated by the EcoBright LED panel and the sensor combination. To achieve this, the testing environment was designed to bridge the gap between theoretical calculations and physical deployment.

Using an ESP32 WROVER-E microcontroller, a hardware simulation was developed to physically mimic human movement. A servo motor was programmed with different algorithmic duty cycles to recreate the exact traffic density, lingering behaviors, and motion characteristics of five real-world commercial environments (School, Fitness, Warehouse, Shopping and Parking).

By actively triggering the physical occupancy sensors under these realistic conditions, the true dynamic response of the system, including its one minute timeout intervals, 50% standby dimming, and complete shut offs could be accurately captured. The analog voltage of the PIR and Microwave sensors were continuously monitored and logged, providing a measurable dataset that directly translates the hardware's performance into quantifiable energy and financial savings for the consumer.

5.2 Stimulus Generation

The PIR sensor detects motion by measuring changes in infrared radiation rather than motion itself. Infrared radiation is a region of the electromagnetic spectrum with wavelengths longer than visible light, typically ranging from approximately 700 nm to 1 mm [10]. PIR sensors used in occupancy detection are designed to respond primarily to long-wave infrared radiation in the range of approximately 8 μm to 14 μm [11]. This wavelength range corresponds closely to the thermal radiation emitted by objects at temperatures near that of the human body.

Human bodies naturally emit infrared radiation due to their surface temperature, typically around 306 K. According to thermal radiation principles, objects at this temperature emit energy primarily in the long-wave infrared region [12]. PIR sensors are tuned to detect changes in this radiation when a warm object moves across the sensor's field of view.

Most conventional light sources operate primarily within the visible spectrum, which spans wavelengths from approximately 400 nm to 700 nm. Since PIR sensors are designed to detect longer infrared wavelengths associated with thermal emission, visible light sources generally do not produce a detectable signal within the operating range of the sensor [10].

To replicate the thermal radiation characteristics of a human body, a controlled infrared stimulus was generated using a PTC (Positive Temperature Coefficient) heating element mounted to an anodized black aluminum plate. The heating element provides a stable heat source, while the anodized black aluminum surface improves thermal emission due to its high infrared emissivity. Dark anodized aluminum surfaces efficiently radiate thermal energy into the surrounding environment, producing a consistent infrared source detectable by PIR sensors [12].

The heated plate was mounted at the end of a servo driven actuator beam. As the servo moved the beam through the sensor's field of view, the heated radiator entered and exited the detection zones of the PIR sensor. This motion created changes in infrared radiation similar to those produced by a moving human occupant, allowing controlled and repeatable stimulus events to be generated during testing.

For the parking garage evaluation using the microwave motion sensor, the same actuator and heated aluminum target were retained in order to maintain consistent stimulus geometry and motion behaviour between sensing configurations. While microwave sensors detect motion through reflected electromagnetic signals rather than infrared radiation, the moving aluminum plate provided a stable reflective surface and consistent physical motion target. Maintaining the same actuator and target ensured that differences observed between PIR and microwave configurations were attributable to the sensing technology rather than changes in the physical test setup.

5.3 Scenario Profiles

The different scenarios being tested can be found below. The implementation for each mode compresses 24 hours of simulation into 8 hours of real life testing to get three days of potential data for the panels. This allows for a higher range of data when decompressed but also accounts for a worst case scenario when the data is left as is. The two scenarios that followed this decompression were the fitness centre and shopping centre cases. The rest of the scenarios tested used the compressed data as normal. By testing for a worst case, the saving numbers can be guaranteed to be closely similar to the simulated values when implementing the same sensor activation settings.

The decompression algorithm works by splitting the 24 hours tested in the lab into three separate 8 hour periods. These 8 hours are used as the basis for a high activity period. The data from the panel power usage is then cut by 50% for the next 8 hours to simulate the early morning and late nights when there is no movement. Finally, another 8 hours of 0 power consumption is added to simulate an overnight shutdown facility. Using this set up, three days can be simulated for the fitness and shopping centre more accurately rather than having each facility running at full capacity for the 24 hour period.

1. **School Zone:**
   The school zone scenario tests an educational environment with periodic high activity movement between class times. The way this is implemented is by having a 5% chance of moment for 16 minutes (simulating students in classrooms), then having a class change for 3.3 minutes, which increases the movement percentage to 94%.
2. **Fitness Centre:**
   The fitness scenario is the first of the adjusted scenarios evaluated. The original tests simulate a high activity gym environment with constant movement. It is implemented by checking every 30 seconds for movement and there is a 60& chance that someone moves. If the program lands within that 60%, the servo will actuate for 15 seconds. This simulates a person or group of people walking under the sensor.
3. **Warehouse**
   The warehouse scenario implements a high activity model to simulate a worst case savings scenario. It can be compared to an active busy warehouse such as an amazon processing facility where there is semi constant movement of employees and equipment. This is implemented in the code by checking for movement every 40 seconds and there is a 30% chance of movement. If the program lands within that 30& range, then the servo will actuate for 8 seconds.
4. **Shopping Centre:**
   The shopping centre scenario is the second adjusted case which follows the same decompression algorithm as the fitness centre. Movement is checked every 20 seconds with a 60% chance of activation. If the program lands within this range, the servo actuates slowly until the next check is done. This ideology simulates constant moving traffic in a shopping mall environment.
5. **Parking Garage:**
   The parking garage scenario has the lowest possibility of activating. The program will check for movement every 45 seconds with a 20% chance of movement. If the program lands within this range, the servo moves for 12 seconds to simulate a car or human

passing by. The parking centre tests were also done with both the PIR and MW sensor to compare savings between the two options.

5.4 Data Collection and Logging

To ensure data integrity and high resolution tracking of the panel's dimming states, the test bench was configured to log hardware events at a continuous 1 Hz sampling rate. Every second, the system records the current simulation profile, the raw analog voltage of the LED driver (acting as a proxy for the dimming state, referenced to a 2.5V maximum), the active motion interval (how many milliseconds the sensor was triggered during that second), and the current physical angle of the servo motor. The 1 Hz reporting frequency is controlled by a dedicated hardware timer interrupt on the ESP32, which executes exactly every 1,000,000 microseconds. To prevent internal clock drift over 24-hour test periods, the testing computer handles absolute timestamping. A Python script reads the serial output and creates an absolute UNIX timestamp and a localized datetime for each incoming row. The serial data stream is parsed and written sequentially into standard `.csv` (Comma-Separated Values) files. Files are named according to the specific testing profile being run (e.g., `SCHOOLTEST1.csv`, `test5Microwave.csv`). Raw CSV logs are written locally to the test bench PC's hard drive in real-time. Upon completion of each test cycle, the raw datasets are immediately duplicated and backed up to a secure cloud directory before being ingested into MATLAB for numerical analysis.

5.5 Energy and Environmental Calculations

Rather than relying on flat estimations or generic 40W label ratings, the energy consumption was calculated through dynamic numerical integration of the raw sensor logs.

- **Energy (kWh) Savings:** The true maximum power draw (P_{max}) of the LED panels was derived analytically using the goniophotometer systems test report data [4] (Nominal Flux ÷ Luminous Efficacy). For every single row in the CSV, a dynamic dimming ratio was established by dividing the recorded LED voltage by the 2.5V reference maximum. The exact energy consumed during that 1-second interval was calculated and summed across the entire dataset (∼90,000 rows per test). This total was then subtracted from a theoretical 24-hour "Always ON" baseline to determine the exact kWh saved.
- **Carbon Footprint and Financial Sources:** To project the raw kWh savings into a

real-world commercial facility impact, standard regional baseline metrics were applied. Financial savings were calculated using an estimated commercial electricity rate of $0.175 CAD/kWh [1]. The greenhouse gas output was calculated using a localized grid emission factor of 185 gCO_2/kWh [2]. These values represent realistic, conservative baselines for a standard commercial building energy audit.

6 Results

The following section summarizes the data collected during the validation testing. It includes the energy consumption, carbon footprint, and financial costs for the tested scenarios, integrating both dynamic dimming states and the decompressed data for high acitvity scenarios. The results have been calculated for multiple wattage (40W, 50W) and color temperatures (35K, 40K, and 50K) based on their specific nominal flux and luminous efficacy ratings (provided by EcoBright). Going forward, the Wk, Mo, and Yr sections of the table represent the weekly, monthly, and yearly panel usage with the sensor, respectively. The Wk(ON), Mo(ON), and Yr(ON) represent the same values but for the base fixture.

6.1 40W Panels

6.1.1 40W 35K CC

Performance metrics for the 40W 35k CC panel (True Wattage: 37.563 W).

Scenario	**Savings**	**Wk**	**Wk (ON)**	**Mo**	**Mo (ON)**	**Yr**	**Yr (ON)**
School	48.97%	3.22	6.31	13.99	27.42	167.91	329.05
Fitness (Adj)	52.52%	3.00	6.31	13.02	27.42	156.23	329.05
Warehouse	35.24%	4.09	6.31	17.76	27.42	213.09	329.05
Shopping (Adj)	52.27%	3.01	6.31	13.09	27.42	157.05	329.05
Parking (PIR)	49.31%	3.20	6.31	13.90	27.42	166.79	329.05
Parking (MW)	62.12%	2.39	6.31	10.39	27.42	124.64	329.05

Table 3: Projected Energy Consumption (kWh) per Fixture - 40W 35k CC

Scenario	Savings	Wk	Wk (ON)	Mo	Mo (ON)	Yr	Yr (ON)
School	48.97%	595.7	1167.4	2588.7	5072.8	31064.0	60873.9
Fitness (Adj)	52.52%	554.3	1167.4	2408.6	5072.8	28902.9	60873.9
Warehouse	35.24%	756.0	1167.4	3285.2	5072.8	39422.0	60873.9
Shopping (Adj)	52.27%	557.2	1167.4	2421.3	5072.8	29055.1	60873.9
Parking (PIR)	49.31%	591.7	1167.4	2571.5	5072.8	30856.8	60873.9
Parking (MW)	62.12%	442.2	1167.4	1921.8	5072.8	23059.0	60873.9

Table 4: Carbon Footprint Summary (gCO_2) per Fixture - 40W 35k CC

Scenario	Savings	Wk ($)	Wk (ON)	Mo ($)	Mo (ON)	Yr ($)	Yr (ON)
School	48.97%	0.56	1.10	2.45	4.80	29.38	57.58
Fitness (Adj)	52.52%	0.52	1.10	2.28	4.80	27.34	57.58
Warehouse	35.24%	0.72	1.10	3.11	4.80	37.29	57.58
Shopping (Adj)	52.27%	0.53	1.10	2.29	4.80	27.48	57.58
Parking (PIR)	49.31%	0.56	1.10	2.43	4.80	29.19	57.58
Parking (MW)	62.12%	0.42	1.10	1.82	4.80	21.81	57.58

Table 5: Financial Cost Summary (CAD) per Fixture - 40W 35k CC

Scenario	Savings	Total kWh Saved	Total $kgCO_2$ Saved	Total CAD Saved
School	48.97%	161,137	29,810	$28,198.92
Fitness (Adj)	52.52%	172,818	31,971	$30,243.20
Warehouse	35.24%	115,959	21,452	$20,292.81
Shopping (Adj)	52.27%	171,996	31,819	$30,099.23
Parking (PIR)	49.31%	162,255	30,017	$28,394.66
Parking (MW)	62.12%	204,411	37,816	$35,771.86

Table 6: Annual Facility Impact Pitch (Scaled to 1,000 Fixtures) - 40W 35k CC

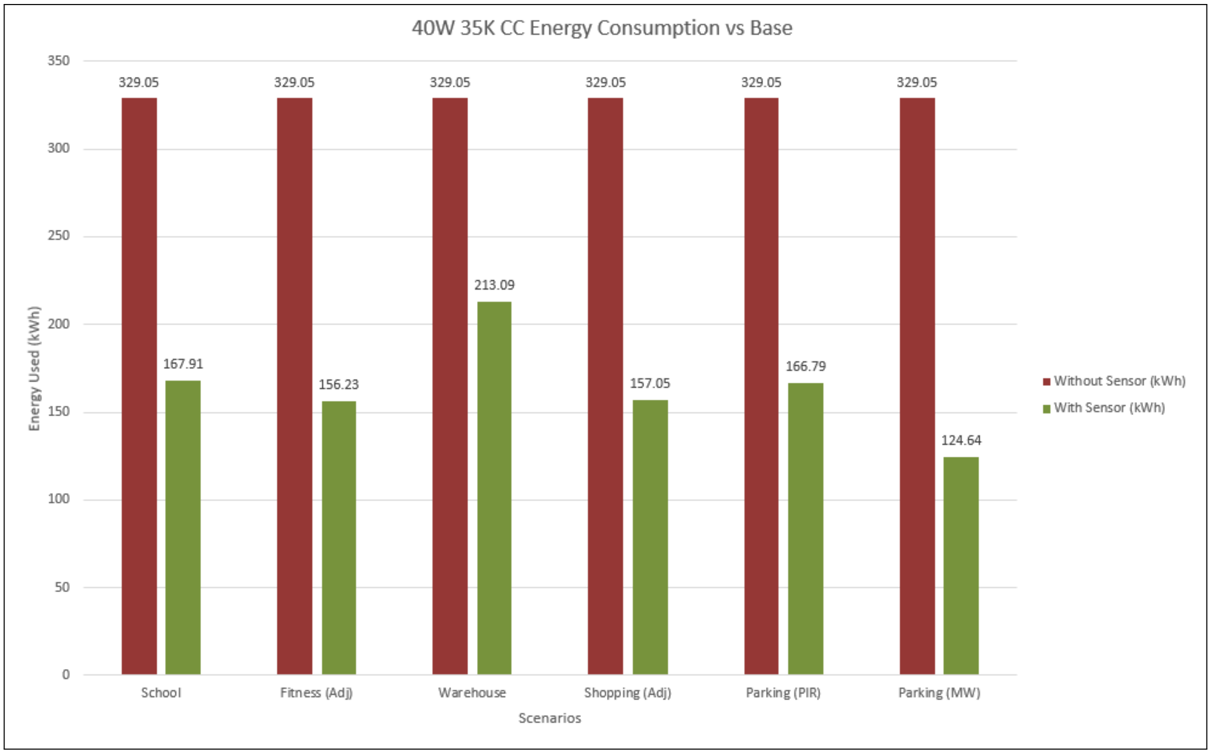

Figure 5: Projected Energy Consumption (Yearly) - 40W 35k CC

6.1.2 40W 40K CC

Performance metrics for the 40W 40K CC panel (True Wattage: 36.365 W).

Scenario	Savings	Wk	Wk (ON)	Mo	Mo (ON)	Yr	Yr (ON)
School	48.97%	3.12	6.11	13.55	26.55	162.56	318.56
Fitness (Adj)	52.52%	2.90	6.11	12.60	26.55	151.25	318.56
Warehouse	35.24%	3.96	6.11	17.19	26.55	206.30	318.56
Shopping (Adj)	52.27%	2.92	6.11	12.67	26.55	152.05	318.56
Parking (PIR)	49.31%	3.10	6.11	13.46	26.55	161.48	318.56
Parking (MW)	62.12%	2.31	6.11	10.06	26.55	120.67	318.56

Table 7: Projected Energy Consumption (kWh) per Fixture - 40W 40K CC

Scenario	Savings	Wk	Wk (ON)	Mo	Mo (ON)	Yr	Yr (ON)
School	48.97%	576.7	1130.2	2506.1	4911.1	30074.2	58933.1
Fitness (Adj)	52.52%	536.6	1130.2	2331.7	4911.1	27982.1	58933.1
Warehouse	35.24%	731.9	1130.2	3180.4	4911.1	38165.7	58933.1
Shopping (Adj)	52.27%	539.4	1130.2	2344.0	4911.1	28129.5	58933.1
Parking (PIR)	49.31%	572.8	1130.2	2489.4	4911.1	29873.7	58933.1
Parking (MW)	62.12%	428.1	1130.2	1860.5	4911.1	22324.0	58933.1

Table 8: Carbon Footprint Summary (gCO_2) per Fixture - 40W 40K CC

Scenario	Savings	Wk ($)	Wk (ON)	Mo ($)	Mo (ON)	Yr ($)	Yr (ON)
School	48.97%	0.55	1.07	2.37	4.65	28.45	55.75
Fitness (Adj)	52.52%	0.51	1.07	2.21	4.65	26.47	55.75
Warehouse	35.24%	0.69	1.07	3.01	4.65	36.10	55.75
Shopping (Adj)	52.27%	0.51	1.07	2.22	4.65	26.61	55.75
Parking (PIR)	49.31%	0.54	1.07	2.35	4.65	28.26	55.75
Parking (MW)	62.12%	0.40	1.07	1.76	4.65	21.12	55.75

Table 9: Financial Cost Summary (CAD) per Fixture - 40W 40K CC

Scenario	Savings	Total kWh Saved	Total $kgCO_2$ Saved	Total CAD Saved
School	48.97%	155,998	28,860	$27,299.70
Fitness (Adj)	52.52%	167,307	30,952	$29,278.75
Warehouse	35.24%	112,260	20,768	$19,645.53
Shopping (Adj)	52.27%	166,511	30,804	$29,139.38
Parking (PIR)	49.31%	157,081	29,060	$27,489.24
Parking (MW)	62.12%	197,889	36,609	$34,630.54

Table 10: Annual Facility Impact (Scaled to 1,000 Fixtures) - 40W 40K CC

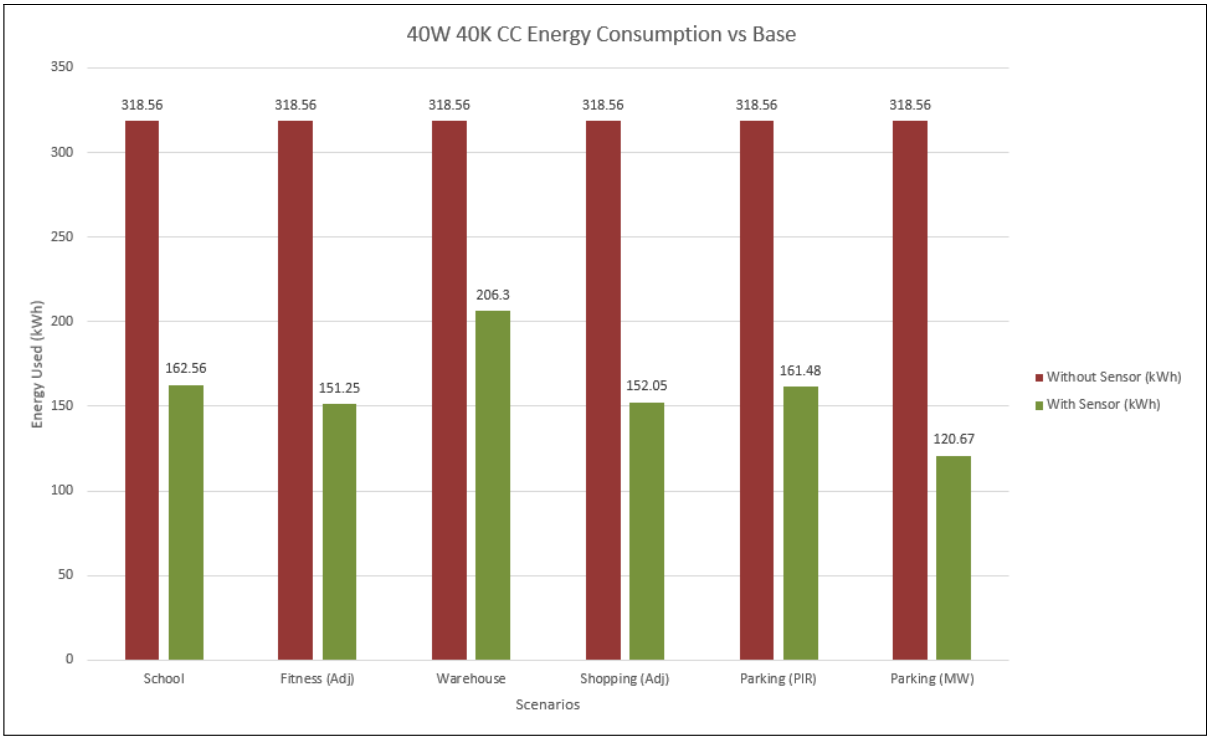

Figure 6: Projected Energy Consumption (Yearly) - 40W 40K CC

6.1.3 40W 50K CC

Performance metrics for the 40W 50k CC panel (True Wattage: 37.208 W).

Scenario	Savings	Wk	Wk (ON)	Mo	Mo (ON)	Yr	Yr (ON)
School	48.97%	3.19	6.25	13.86	27.16	166.32	325.94
Fitness (Adj)	52.52%	2.97	6.25	12.90	27.16	154.76	325.94
Warehouse	35.24%	4.05	6.25	17.59	27.16	211.08	325.94
Shopping (Adj)	52.27%	2.98	6.25	12.96	27.16	155.57	325.94
Parking (PIR)	49.31%	3.17	6.25	13.77	27.16	165.22	325.94
Parking (MW)	62.12%	2.37	6.25	10.29	27.16	123.47	325.94

Table 11: Projected Energy Consumption (kWh) per Fixture - 40W 50k CC

Scenario	Savings	Wk	Wk (ON)	Mo	Mo (ON)	Yr	Yr (ON)
School	48.97%	590.1	1156.4	2564.2	5024.9	30770.4	60299.1
Fitness (Adj)	52.52%	549.0	1156.4	2385.8	5024.9	28629.6	60299.1
Warehouse	35.24%	748.8	1156.4	3254.1	5024.9	39049.2	60299.1
Shopping (Adj)	52.27%	551.9	1156.4	2398.4	5024.9	28780.4	60299.1
Parking (PIR)	49.31%	586.1	1156.4	2547.2	5024.9	30564.9	60299.1
Parking (MW)	62.12%	438.0	1156.4	1903.6	5024.9	22841.0	60299.1

Table 12: Carbon Footprint Summary (gCO_2) per Fixture - 40W 50k CC

Scenario	Savings	Wk ($)	Wk (ON)	Mo ($)	Mo (ON)	Yr ($)	Yr (ON)
School	48.97%	0.56	1.09	2.43	4.75	29.11	57.04
Fitness (Adj)	52.52%	0.52	1.09	2.26	4.75	27.08	57.04
Warehouse	35.24%	0.71	1.09	3.08	4.75	36.94	57.04
Shopping (Adj)	52.27%	0.52	1.09	2.27	4.75	27.22	57.04
Parking (PIR)	49.31%	0.55	1.09	2.41	4.75	28.91	57.04
Parking (MW)	62.12%	0.41	1.09	1.80	4.75	21.61	57.04

Table 13: Financial Cost Summary (CAD) per Fixture - 40W 50k CC

Scenario	Savings	Total kWh Saved	Total $kgCO_2$ Saved	Total CAD Saved
School	48.97%	159,615	29,529	$27,932.61
Fitness (Adj)	52.52%	171,185	31,669	$29,957.44
Warehouse	35.24%	114,863	21,250	$20,101.11
Shopping (Adj)	52.27%	170,371	31,519	$29,814.99
Parking (PIR)	49.31%	160,723	29,734	$28,126.47
Parking (MW)	62.12%	202,476	37,458	$35,433.26

Table 14: Annual Facility Impact (Scaled to 1,000 Fixtures) - 40W 50k CC

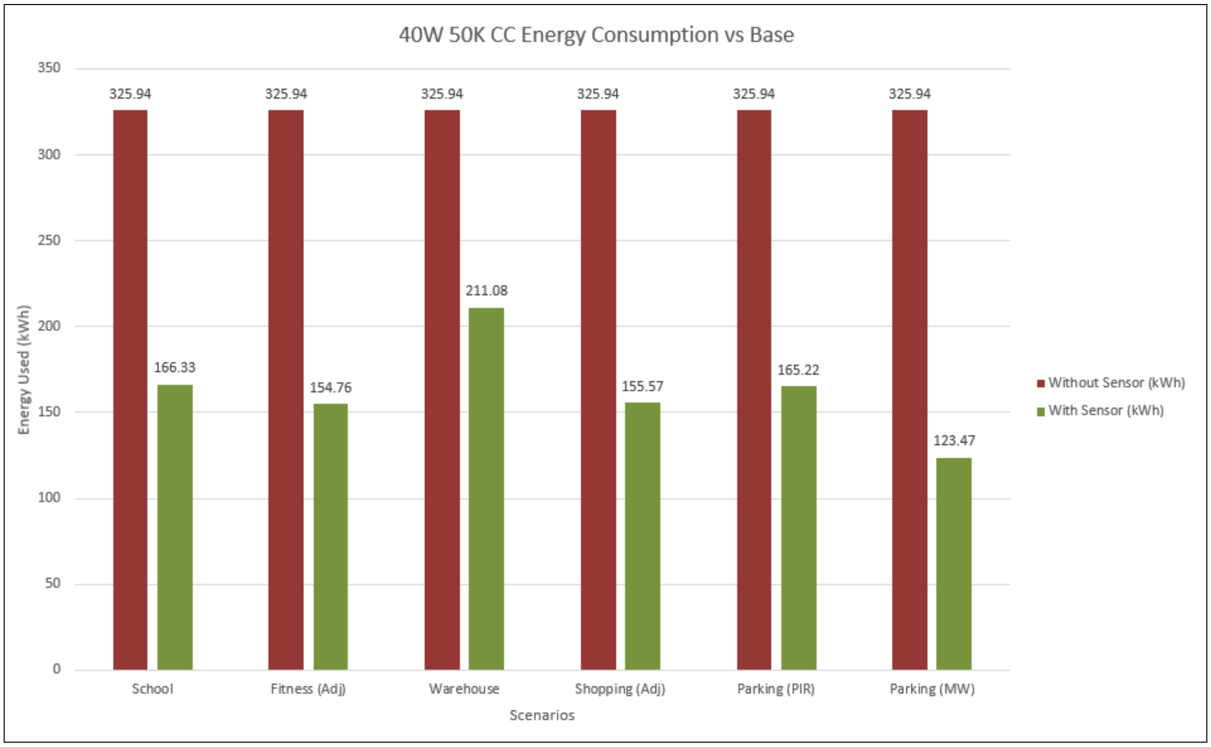

Figure 7: Projected Energy Consumption (Yearly) - 40W 50k CC

6.2 50W Panels

6.2.1 50W 35K CC

Performance metrics for the 50W 35k CC panel (True Wattage: 47.364 W).

Scenario	Savings	Wk	Wk (ON)	Mo	Mo (ON)	Yr	Yr (ON)
School	48.97%	4.06	7.96	17.64	34.58	211.72	414.91
Fitness (Adj)	52.52%	3.78	7.96	16.42	34.58	197.00	414.91
Warehouse	35.24%	5.15	7.96	22.39	34.58	268.69	414.91
Shopping (Adj)	52.27%	3.80	7.96	16.50	34.58	198.04	414.91
Parking (PIR)	49.31%	4.03	7.96	17.53	34.58	210.31	414.91
Parking (MW)	62.12%	3.01	7.96	13.10	34.58	157.17	414.91

Table 15: Projected Energy Consumption (kWh) per Fixture - 50W 35k CC

Scenario	Savings	Wk	Wk (ON)	Mo	Mo (ON)	Yr	Yr (ON)
School	48.97%	751.1	1472.1	3263.8	6397.0	39168.3	76758.8
Fitness (Adj)	52.52%	698.9	1472.1	3037.1	6397.0	36444.6	76758.8
Warehouse	35.24%	953.2	1472.1	4142.2	6397.0	49708.2	76758.8
Shopping (Adj)	52.27%	702.5	1472.1	3053.1	6397.0	36636.5	76758.8
Parking (PIR)	49.31%	746.1	1472.1	3242.3	6397.0	38907.5	76758.8
Parking (MW)	62.12%	557.6	1472.1	2423.2	6397.0	29075.7	76758.8

Table 16: Carbon Footprint Summary (gCO_2) per Fixture - 50W 35k CC

Scenario	Savings	Wk ($)	Wk (ON)	Mo ($)	Mo (ON)	Yr ($)	Yr (ON)
School	48.97%	0.71	1.39	3.09	6.05	37.05	72.61
Fitness (Adj)	52.52%	0.66	1.39	2.87	6.05	34.47	72.61
Warehouse	35.24%	0.90	1.39	3.92	6.05	47.02	72.61
Shopping (Adj)	52.27%	0.66	1.39	2.89	6.05	34.66	72.61
Parking (PIR)	49.31%	0.71	1.39	3.07	6.05	36.80	72.61
Parking (MW)	62.12%	0.53	1.39	2.29	6.05	27.50	72.61

Table 17: Financial Cost Summary (CAD) per Fixture - 50W 35k CC

Scenario	Savings	Total kWh Saved	Total $kgCO_2$ Saved	Total CAD Saved
School	48.97%	203,192	37,591	$35,558.60
Fitness (Adj)	52.52%	217,915	40,314	$38,135.08
Warehouse	35.24%	146,220	27,051	$25,588.45
Shopping (Adj)	52.27%	216,879	40,123	$37,953.76
Parking (PIR)	49.31%	204,602	37,851	$35,805.28
Parking (MW)	62.12%	257,748	47,683	$45,105.86

Table 18: Annual Facility Impact (Scaled to 1,000 Fixtures) - 50W 35k CC

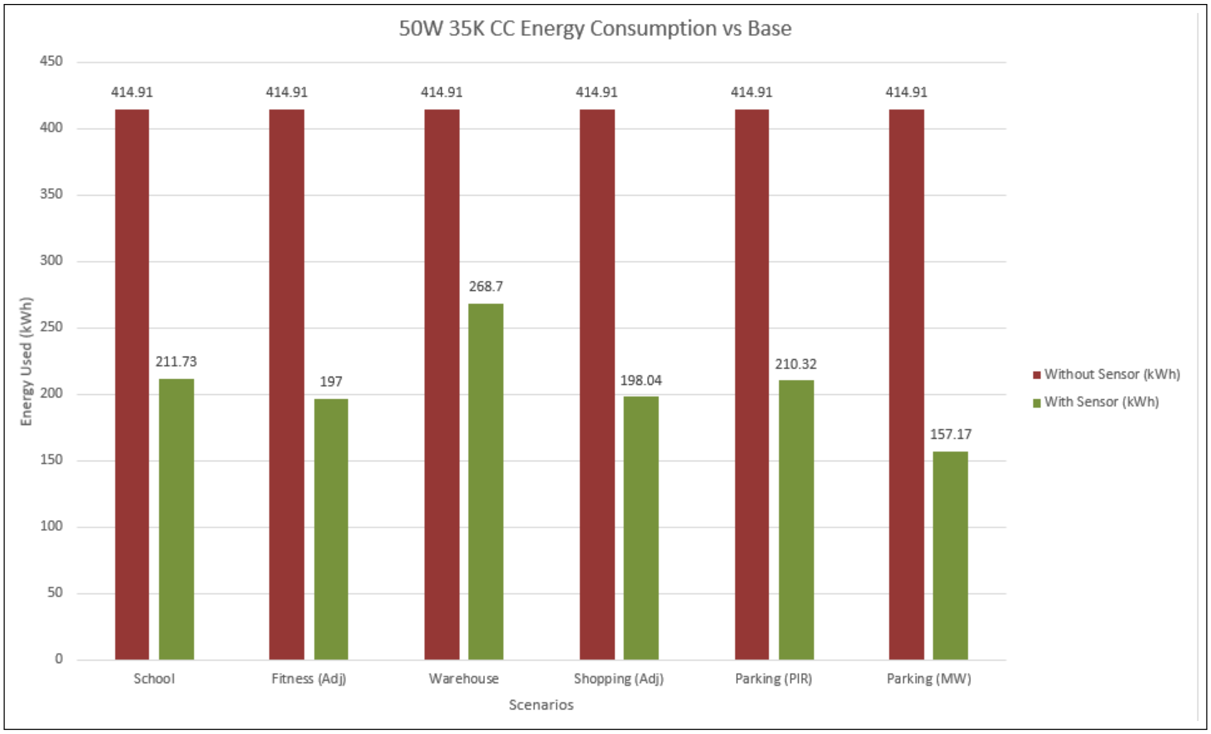

Figure 8: Projected Energy Consumption (Yearly) - 50W 35k CC

6.2.2 50W 40K CC

Performance metrics for the 50W 40k CC panel (True Wattage: 45.621 W).

Scenario	Savings	Wk	Wk (ON)	Mo	Mo (ON)	Yr	Yr (ON)
School	48.97%	3.91	7.66	16.99	33.30	203.93	399.64
Fitness (Adj)	52.52%	3.64	7.66	15.81	33.30	189.75	399.64
Warehouse	35.24%	4.96	7.66	21.57	33.30	258.80	399.64
Shopping (Adj)	52.27%	3.66	7.66	15.89	33.30	190.75	399.64
Parking (PIR)	49.31%	3.88	7.66	16.88	33.30	202.58	399.64
Parking (MW)	62.12%	2.90	7.66	12.61	33.30	151.38	399.64

Table 19: Projected Energy Consumption (kWh) per Fixture - 50W 40k CC

Scenario	Savings	Wk	Wk (ON)	Mo	Mo (ON)	Yr	Yr (ON)
School	48.97%	723.5	1418.0	3143.7	6161.7	37727.6	73933.4
Fitness (Adj)	52.52%	673.2	1418.0	2925.3	6161.7	35104.3	73933.4
Warehouse	35.24%	918.1	1418.0	3989.8	6161.7	47878.7	73933.4
Shopping (Adj)	52.27%	676.7	1418.0	2940.8	6161.7	35289.1	73933.4
Parking (PIR)	49.31%	718.6	1418.0	3122.9	6161.7	37476.3	73933.4
Parking (MW)	62.12%	537.1	1418.0	2334.0	6161.7	28005.8	73933.4

Table 20: Carbon Footprint Summary (gCO_2) per Fixture - 50W 40k CC

Scenario	Savings	Wk ($)	Wk (ON)	Mo ($)	Mo (ON)	Yr ($)	Yr (ON)
School	48.97%	0.68	1.34	2.97	5.83	35.69	69.94
Fitness (Adj)	52.52%	0.64	1.34	2.77	5.83	33.21	69.94
Warehouse	35.24%	0.87	1.34	3.77	5.83	45.29	69.94
Shopping (Adj)	52.27%	0.64	1.34	2.78	5.83	33.38	69.94
Parking (PIR)	49.31%	0.68	1.34	2.95	5.83	35.45	69.94
Parking (MW)	62.12%	0.51	1.34	2.21	5.83	26.49	69.94

Table 21: Financial Cost Summary (CAD) per Fixture - 50W 40k CC

Scenario	Savings	Total kWh Saved	Total $kgCO_2$ Saved	Total CAD Saved
School	48.97%	195,715	36,207	$34,250.08
Fitness (Adj)	52.52%	209,896	38,831	$36,731.81
Warehouse	35.24%	140,841	26,056	$24,647.24
Shopping (Adj)	52.27%	208,898	38,646	$36,557.17
Parking (PIR)	49.31%	197,073	36,458	$34,487.73
Parking (MW)	62.12%	248,261	45,928	$43,445.69

Table 22: Annual Facility Impact (Scaled to 1,000 Fixtures) - 50W 40k CC

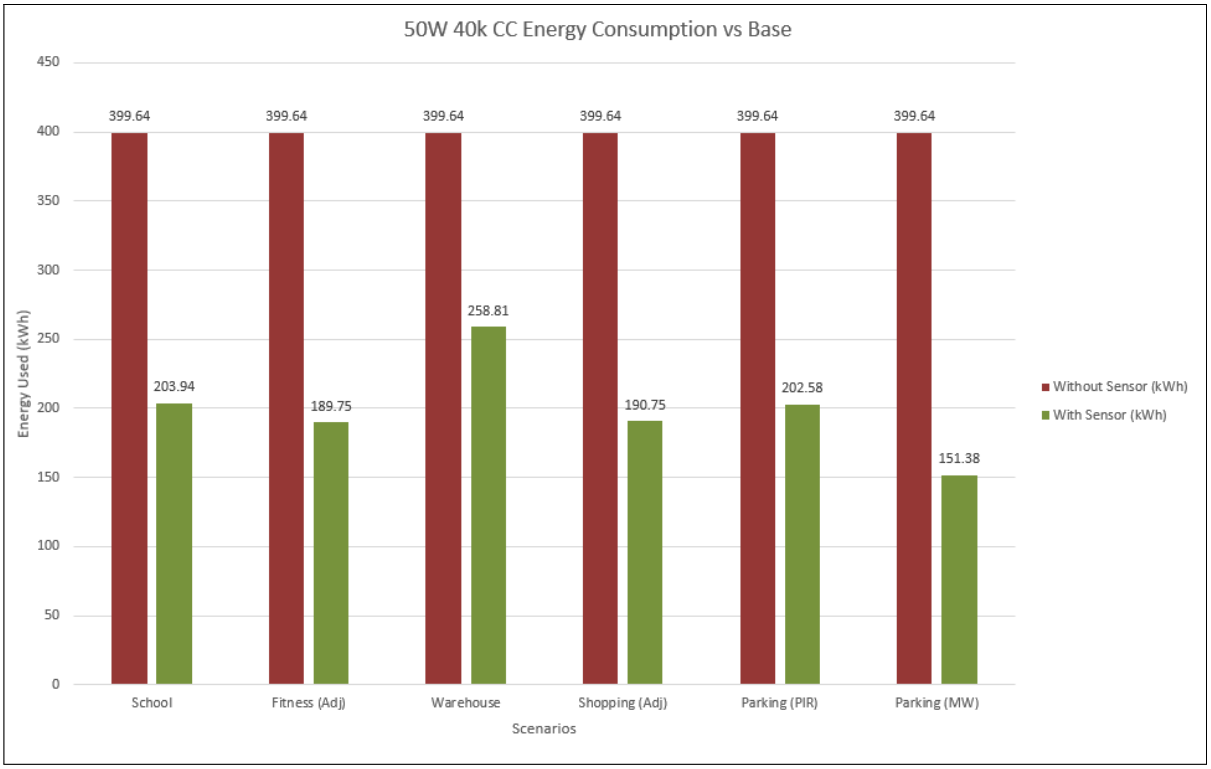

Figure 9: Projected Energy Consumption (Yearly) - 50W 40k CC

6.2.3 50W 50K CC

Performance metrics for the 50W 50k CC panel (True Wattage: 47.195 W).

Scenario	Savings	Wk	Wk (ON)	Mo	Mo (ON)	Yr	Yr (ON)
School	48.97%	4.05	7.93	17.58	34.45	210.97	413.43
Fitness (Adj)	52.52%	3.77	7.93	16.36	34.45	196.30	413.43
Warehouse	35.24%	5.13	7.93	22.31	34.45	267.73	413.43
Shopping (Adj)	52.27%	3.78	7.93	16.44	34.45	197.33	413.43
Parking (PIR)	49.31%	4.02	7.93	17.46	34.45	209.56	413.43
Parking (MW)	62.12%	3.00	7.93	13.05	34.45	156.61	413.43

Table 23: Projected Energy Consumption (kWh) per Fixture - 50W 50k CC

Scenario	Savings	Wk	Wk (ON)	Mo	Mo (ON)	Yr	Yr (ON)
School	48.97%	748.5	1466.9	3252.1	6374.1	39028.5	76484.5
Fitness (Adj)	52.52%	696.5	1466.9	3026.3	6374.1	36314.5	76484.5
Warehouse	35.24%	949.8	1466.9	4127.4	6374.1	49530.7	76484.5
Shopping (Adj)	52.27%	700.0	1466.9	3042.2	6374.1	36505.6	76484.5
Parking (PIR)	49.31%	743.4	1466.9	3230.7	6374.1	38768.6	76484.5
Parking (MW)	62.12%	555.6	1466.9	2414.5	6374.1	28971.9	76484.5

Table 24: Carbon Footprint Summary (gCO_2) per Fixture - 50W 50k CC

Scenario	Savings	Wk ($)	Wk (ON)	Mo ($)	Mo (ON)	Yr ($)	Yr (ON)
School	48.97%	0.71	1.39	3.08	6.03	36.92	72.35
Fitness (Adj)	52.52%	0.66	1.39	2.86	6.03	34.35	72.35
Warehouse	35.24%	0.90	1.39	3.90	6.03	46.85	72.35
Shopping (Adj)	52.27%	0.66	1.39	2.88	6.03	34.53	72.35
Parking (PIR)	49.31%	0.70	1.39	3.06	6.03	36.67	72.35
Parking (MW)	62.12%	0.53	1.39	2.28	6.03	27.41	72.35

Table 25: Financial Cost Summary (CAD) per Fixture - 50W 50k CC

Scenario	Savings	Total kWh Saved	Total $kgCO_2$ Saved	Total CAD Saved
School	48.97%	202,466	37,456	$35,431.57
Fitness (Adj)	52.52%	217,137	40,170	$37,998.96
Warehouse	35.24%	145,698	26,954	$25,497.10
Shopping (Adj)	52.27%	216,105	39,979	$37,818.31
Parking (PIR)	49.31%	203,872	37,716	$35,677.52
Parking (MW)	62.12%	256,828	47,513	$44,944.82

Table 26: Annual Facility Impact (Scaled to 1,000 Fixtures) - 50W 50k CC

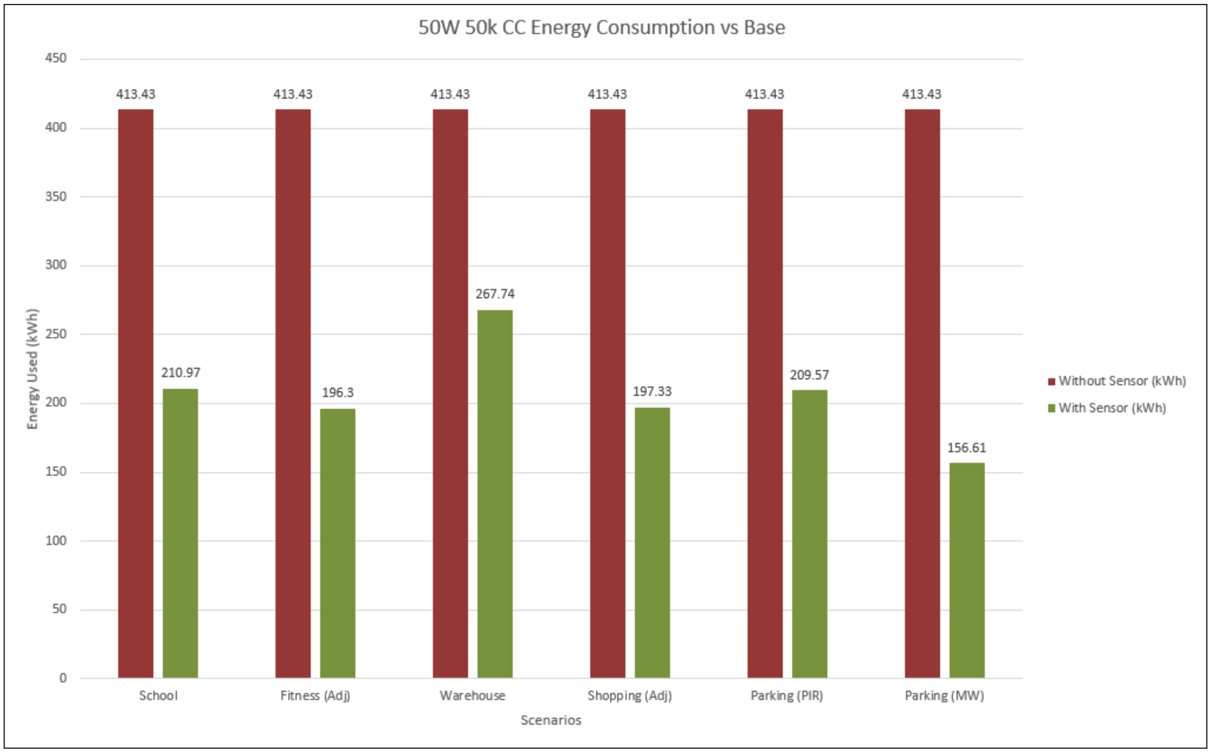

Figure 10: Projected Energy Consumption (Yearly) - 50W 50k CC

6.3 High-Output Panels (Estimated 80W and 125W)

DISCLAIMER: The following energy, environmental, and financial projections for the 80W and 125W LED panels are calculated using their flat nominal wattages. Because precise photometric data (nominal flux and luminous efficacy) was unavailable at the time of testing, these calculations do not mathematically isolate the driver efficiency losses. As a result, there is an estimated 9-12% margin of error regarding the absolute volumetric values presented below. However, the fractional percentage savings relative to the baseline remain identical to prior tested hardware.

6.3.1 80W Flat Projection

Performance metrics utilizing an estimated baseline of 80 W.

Scenario	Savings	Wk	Wk (ON)	Mo	Mo (ON)	Yr	Yr (ON)
School	48.97%	6.86	13.44	29.80	58.40	357.62	700.80
Fitness (Adj)	52.52%	6.38	13.44	27.73	58.40	332.74	700.80
Warehouse	35.24%	8.70	13.44	37.82	58.40	453.84	700.80
Shopping (Adj)	52.27%	6.41	13.44	27.87	58.40	334.49	700.80
Parking (PIR)	49.31%	6.81	13.44	29.60	58.40	355.24	700.80
Parking (MW)	62.12%	5.09	13.44	22.12	58.40	265.46	700.80

Table 27: Projected Energy Consumption (kWh) per Fixture - 80W

Scenario	Savings	Wk	Wk (ON)	Mo	Mo (ON)	Yr	Yr (ON)
School	48.97%	1268.8	2486.4	5513.3	10804.0	66159.4	129648.0
Fitness (Adj)	52.52%	1180.5	2486.4	5129.7	10804.0	61556.9	129648.0
Warehouse	35.24%	1610.2	2486.4	6996.7	10804.0	83960.0	129648.0
Shopping (Adj)	52.27%	1186.8	2486.4	5156.8	10804.0	61881.0	129648.0
Parking (PIR)	49.31%	1260.4	2486.4	5476.5	10804.0	65718.7	129648.0
Parking (MW)	62.12%	941.9	2486.4	4092.8	10804.0	49110.6	129648.0

Table 28: Carbon Footprint Summary (gCO_2) per Fixture - 80W

Scenario	Savings	Wk ($)	Wk (ON)	Mo ($)	Mo (ON)	Yr ($)	Yr (ON)
School	48.97%	1.20	2.35	5.21	10.22	62.58	122.64
Fitness (Adj)	52.52%	1.12	2.35	4.85	10.22	58.23	122.64
Warehouse	35.24%	1.52	2.35	6.62	10.22	79.42	122.64
Shopping (Adj)	52.27%	1.12	2.35	4.88	10.22	58.54	122.64
Parking (PIR)	49.31%	1.19	2.35	5.18	10.22	62.17	122.64
Parking (MW)	62.12%	0.89	2.35	3.87	10.22	46.46	122.64

Table 29: Financial Cost Summary (CAD) per Fixture - 80W

Scenario	Savings	Total kWh Saved	Total $kgCO_2$ Saved	Total CAD Saved
School	48.97%	343,182	63,489	$60,056.81
Fitness (Adj)	52.52%	368,060	68,091	$64,410.53
Warehouse	35.24%	246,962	45,688	$43,218.31
Shopping (Adj)	52.27%	366,308	67,767	$64,103.96
Parking (PIR)	49.31%	345,565	63,929	$60,473.80
Parking (MW)	62.12%	435,337	80,537	$76,183.97

Table 30: Annual Facility Impact Pitch (Scaled to 1,000 Fixtures) - 80W

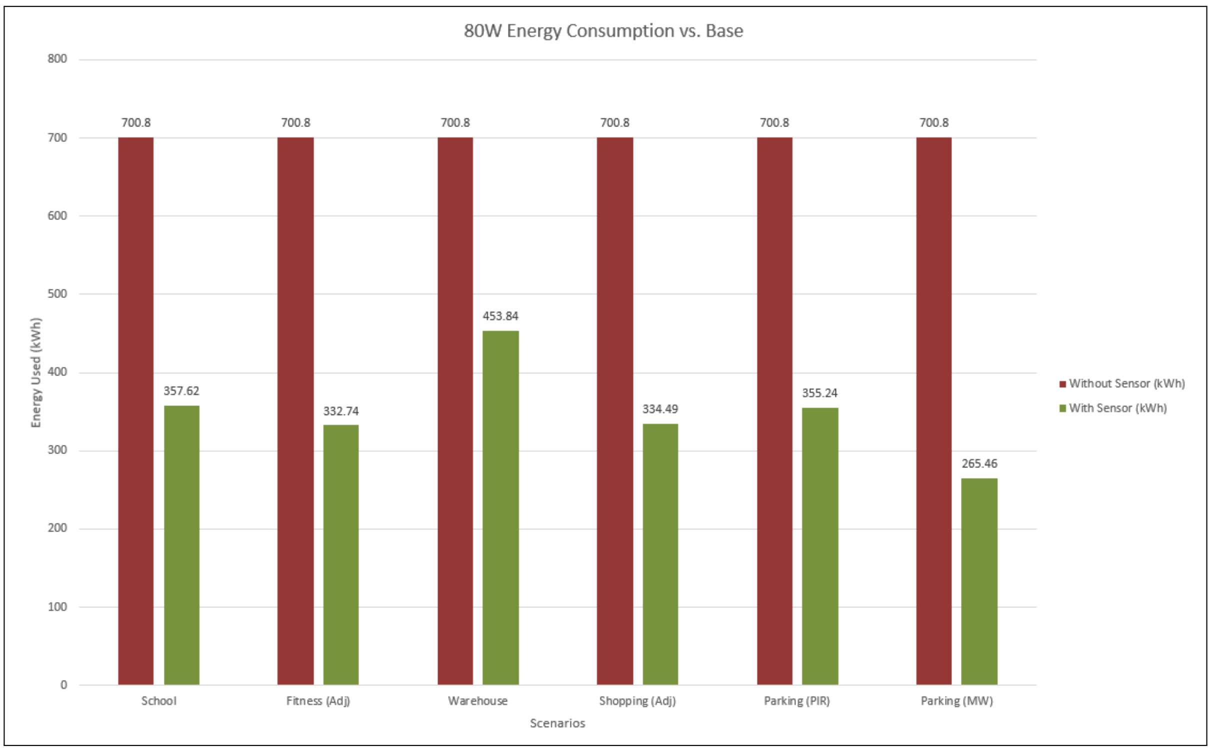

Figure 11: Projected Energy Consumption - 80W

6.3.2 125W Flat Projection

Performance metrics utilizing an estimated baseline of 125 W.

Scenario	Savings	Wk	Wk (ON)	Mo	Mo (ON)	Yr	Yr (ON)
School	48.97%	10.72	21.00	46.56	91.25	558.78	1095.00
Fitness (Adj)	52.52%	9.97	21.00	43.32	91.25	519.90	1095.00
Warehouse	35.24%	13.60	21.00	59.09	91.25	709.12	1095.00
Shopping (Adj)	52.27%	10.02	21.00	43.55	91.25	522.64	1095.00
Parking (PIR)	49.31%	10.65	21.00	46.26	91.25	555.06	1095.00
Parking (MW)	62.12%	7.95	21.00	34.56	91.25	414.79	1095.00

Table 31: Projected Energy Consumption (kWh) per Fixture - 125W

Scenario	Savings	Wk	Wk (ON)	Mo	Mo (ON)	Yr	Yr (ON)
School	48.97%	1982.5	3885.0	8614.5	16881.2	103374.0	202575.0
Fitness (Adj)	52.52%	1844.6	3885.0	8015.2	16881.2	96182.7	202575.0
Warehouse	35.24%	2515.9	3885.0	10932.3	16881.2	131187.5	202575.0
Shopping (Adj)	52.27%	1854.4	3885.0	8057.5	16881.2	96689.1	202575.0
Parking (PIR)	49.31%	1969.4	3885.0	8557.0	16881.2	102685.5	202575.0
Parking (MW)	62.12%	1471.7	3885.0	6394.9	16881.2	76735.3	202575.0

Table 32: Carbon Footprint Summary (gCO_2) per Fixture - 125W

Scenario	Savings	Wk ($)	Wk (ON)	Mo ($)	Mo (ON)	Yr ($)	Yr (ON)
School	48.97%	1.88	3.68	8.15	15.97	97.79	191.62
Fitness (Adj)	52.52%	1.74	3.68	7.58	15.97	90.98	191.62
Warehouse	35.24%	2.38	3.68	10.34	15.97	124.10	191.62
Shopping (Adj)	52.27%	1.75	3.68	7.62	15.97	91.46	191.62
Parking (PIR)	49.31%	1.86	3.68	8.09	15.97	97.13	191.62
Parking (MW)	62.12%	1.39	3.68	6.05	15.97	72.59	191.62

Table 33: Financial Cost Summary (CAD) per Fixture - 125W

Scenario	Savings	Total kWh Saved	Total $kgCO_2$ Saved	Total CAD Saved
School	48.97%	536,222	99,201	$93,838.77
Fitness (Adj)	52.52%	575,094	106,392	$100,641.45
Warehouse	35.24%	385,878	71,387	$67,528.60
Shopping (Adj)	52.27%	572,356	105,886	$100,162.43
Parking (PIR)	49.31%	539,945	99,890	$94,490.31
Parking (MW)	62.12%	680,214	125,840	$119,037.45

Table 34: Annual Facility Impact Pitch (Scaled to 1,000 Fixtures) - 125W

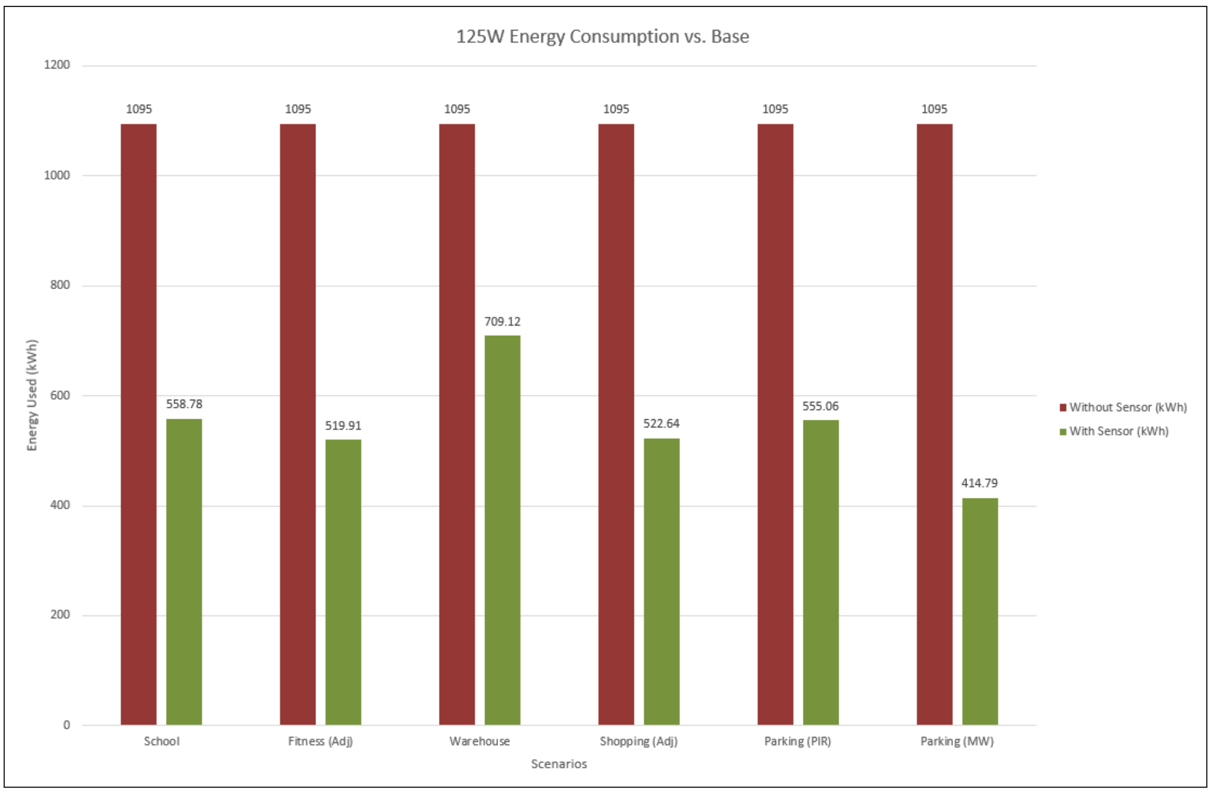

Figure 12: Projected Energy Consumption - 125W

7 Conclusions

The validation testing of the EcoBright motion sensing LED lighting system successfully met all primary project requirements. By evaluating the system under a highly controlled, continuous 1 Hz hardware simulation, the test bench accurately verified both the physical detection capabilities of the sensors and the subsequent dimming logic of the LED drivers across five distinct commercial scenarios.

Overall, the system passed all functional control and detection criteria. Both the PIR and microwave sensor configurations responded reliably to the thermal and physical stimulus generated by the test actuator. The dynamic dimming, standby states, and complete shut-off timeouts executed precisely according to the programmed control behaviours. No system failures, missed detection events, or unprompted false triggers were observed during the evaluation periods, meaning the hardware's operational performance can be validated without conditional caveats.

The continuous logging data strongly supports the deployment of these occupancy based control systems to achieve substantial energy reductions. Depending on the scenario and ambient traffic patterns, the system demonstrated energy savings ranging from a conservative 35.24% in high activity warehouse environments to 62.12% in low activity microwave sensed parking garages. When scaled to a typical commercial installation of 1,000 fixtures, the data proves that this technology yields exceptional utility: avoiding up to 125.84 metric tons of CO_2 equivalent emissions and generating up to $119,037.45 CAD in annual operational savings per facility. Ultimately, the empirical results confirm that EcoBright's dynamic control system is a highly effective, ready to deploy solution for mitigating commercial energy waste.

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