Figure 1 GUI for LED iBond advanced Light Control, Zones and scenes based light management and maintenance.

Project title:

LED Light as IoT infrastructure for building and industrial applications

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Table of Contents

1. Summary in Danish

Projektet har haft to faser med to forskellige omfang og mål. De to omfang er meget indbyrdes forbundne fra et teknologisk synspunkt, og de mange resultater og arbejde relateret til Omfang 1 har været en afgørende trædesten for de vellykkede resultater af Omfang 2.

Omfang 1 - LED-lys som IoT-infrastruktur til bygnings- og industrielle anvendelser

Projektets første fase har haft til formål at opbygge et intelligent LED-infrastruktursystem, der er i stand til at understøtte og samarbejde med enhedsproducenter. Projektet har været en udvidelse af LED iBonds patenterede lys-teknologi kaldet TRACY, der er et modulært lampekoncept.

Projektet havde til formål at udvide mulighederne inden for intelligent belysning med en dobbeltfunktionel LED-panel, der fungerer som infrastruktur for tilkoblede sensorer og enheder i kommercielle og industrielle applikationer. Den intelligente belysning var tænkt som baseret på modulære lysarmaturer, der leverer den centrale IoT-infrastruktur i både nye og eksisterende bygninger. Visionen var en samlet installation af IoT-enheder såsom lyssensorer, temperatur- og luftfugtighedssensorer, kameraer og røgalarmer samt overvågning og dataindsamling.

Omfang 1 - Resultater

Projektet har vist, at brugen af Tracy som infrastruktur udover elektrisk forsyning har vist sig at være uhensigtsmæssig. Dette skyldes delvist den lave båndbredde på infrastrukturen baseret på TRACY lyspanelet (på grund af høj kapacitet) og delvist på grund af en dyr og kompliceret løsning til adskillelse af data over TRACY lyspanelet. Desuden er den faktiske industristandard i dag trådløs kommunikation, hvilket har vist sig at være mere egnet til IoT i bygninger.

Konklusion var, at den kommercielle attraktivitet af den udviklede løsning, som forestillet i begyndelsen af projektet, var for lav og som følge heraf ændrede projektets omfang sig til omfang 2.

Trods denne konklusion om at ændre omfanget, har arbejdet med omfang 1 leveret betydelige resultater, der har dannet platformen for arbejdet i omfang 2.

Nogle af hovedresultaterne af Omfang 1 er:

Software - bruges til avanceret lysstyring i smarte bygninger:

- Udvikling af software til LED iBond hardware Controller til at fungere autonomt som intelligent controller med forskellige sensorer. Softwaren er åben for trådløst tilsluttede sensorer af de mest "standard" kommunikationsprotokoller.
- Software til LED iBond Backend (cloud-tjeneste): håndterer alle sensordata og alle operative enheder og sensorer. Dette er også, hvor programmeringen af handlinger finder sted afhængigt af data modtaget fra forskellige sensorer tilsluttet systemet.
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Hardware - TRACY-portefølje:

- Omkostningsreduktion og opgraderet LED-teknologi (24VDC/højere energi effektivitet)
- Systemkomponenter til nem tilpasning til udvalgte markeder
- Enkelt sensorprogram til autonom lysstyring
- IP67 vand- og støvtæt

Omfang 2 - Tracy- og Gracy-hardware- og softwareplatform til energioptimering i vertikal og indendørs landbrug ved intelligent regulering af lys og andre vækstparametre for at optimere udbyttet fra vertikale og indendørs gårde ved brug af kunstigt lys.

Projektets anden fase har haft til formål at tilføre værdi til indendørs landbrug ved optimeret belysning og intelligent regulering af sådan lys. LED iBonds TRACY- og GRACY-lampe-teknologi er blevet modificeret og optimeret til de specifikke behov i forskellige anvendelser inden for indendørs landbrug.

Sådanne anvendelser er dyrkning af f.eks. salat, jordbær og cannabis. Teknologien er blevet optimeret til at passe til de forskellige typer af tekniske løsninger der anvendes i forskellige farme rundt om i verden. Sådanne løsninger har fx været containere til vanilje, tårne til urter, transportvogne brugt til grønne blade og vækstlys til større drivhuse.

Omfang 2 - Resultater

Baseret på engagement med industrien har projektet vist, at overvågning og kontrol af klimaet i dagens indendørs farme og drivhuse finder sted på stor skala, dvs. for hver sektion af en drivhuskompleks (f.eks. en sektion på 10x100 meter), og kontrollen og justeringen af fx temperatur, luftfugtighed, vanding osv. er baseret på den enkelte farms historiske erfaring.

Overvågning af planters sundhed og kvalitet er baseret på gartnerens egen inspektion (fx berøring og udseende). Industrien er generelt ikke datadrevet på nogen måde. Resultaterne af projektet har vist, at brugen af lamper med det rigtige og optimerede lyspektrum kan øge udbyttet betydeligt (+30%), og potentialet (energibesparelse eller øget produktion med samme energi) af den avancerede kontrol af vækstmiljøet er enorm.

Projektet har også vist, at den første generation af LED-vækstlamper (periode 2015-22) har vist sig at være af lav kvalitet, der ikke holder længe (brænder ud), og de giver lav lyshomogenitet. Gartnerne har ikke set LED som moden teknologi, og >95% af alle lamper i den danske drivhusindustri er gamle traditionelle HPS-lamper med lav energieffektivitet. Manglen på gode LED-lamper har forsinket overgangen fra de gamle HPS/natriumlamper til energibesparende LED-teknologi. Dog er industrien klar til overgangen, når den rette lampe er tilgængelig på markedet.

Desuden har projektet vist, at brugen af billige standard sensorer (f.eks. for CO2, temperatur, luftfugtighed) er velegnede til storskala-udrulning i indendørs gårde, hvis den rette og applikationsspecifikke software bliver tilgængelig.

Nogle af hovedresultaterne af Omfang 2 er:

Software - Avanceret lysstyring og dataindsamling i indendørs gårde:

- Sky Fields - LED iBonds could-løsning, hvor data fra vækstfasen og sensorer i vækstfeltet opbevares. Løsningen forbinder også eksterne IoT-data såsom vejrudsigter og energipriser for at påvirke kontrolalgoritmer og handlinger for at minimere CO2.
- Support til forskellige sensorer og kameraer brugt til in situ-overvågning.
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Hardware - HORTISAPER toplighting-portefølje:

- Markedsledende toplight-løsning til drivhuse.
- Toplight-løsning med markedsledende effektivitet (umol/J), lysets ensartethed (på grund af patenteret - ventende - optikteknologi og design)
- Meget omkostningseffektivt design (DFM) - med brug af de absolut optimale fremstillingsteknologier til hele lampen.
- Bæredygtigt design - produktet understøtter reservedelsplaner - og kan helt adskilles i materielle fraktioner.
- Spar 25+% i energi sammenlignet med de bedste Natrium-lamper på markedet.

Perspektiver

Projektet har givet LED iBond meget vigtig viden både fra et teknisk og markedsorienteret perspektiv. Under projektet og baseret på kundeevaluering har LED iBond vurderet den kommercielle attraktivitet af forskellige kundesegmenter og nødvendige løsninger for at blive succesfuld og konkurrencedygtig.
Som resultat af projektet mener LED iBond, at brugen af avanceret LED-belysning kræver sofistikerede softwarestyringsløsninger for at høste det fulde potentiale af energibesparelsen og værdien af LED-belysningshardwaren.

Derudover mener LED iBond, at applikationsspecifikke løsninger, der kombinerer højt optimerede LED-lys med avanceret software, er afgørende for at være konkurrencedygtig på det globale marked.

Resultaterne fra projektet indikerer klart, at der er attraktive muligheder med sådanne løsninger inden for to specifikke segmenter:

- Indendørs landbrug til plante- og fødevareproduktion
- Parkeringsfaciliteter (Parkeringshuse og solbilporte)

Især det indendørs landbrugsmarked er attraktivt, da værdien af avancerede softwareløsninger kan have meget høj værdi på at minimere energiforbrug og øge farmenes produktion.

Resultaterne af projektet har ført til udvikling af specifikke produkter, der nu tilbydes af LED iBond.

2. Summary in English

The project has had two phases with two different scopes. The two scopes are highly interrelated from a technology point of view and the great results and work related to Scope 1, has been an instrumental steppingstone for the successful results of Scope 2.

Scope 1 - *LED Light as IoT infrastructure for building and industrial applications*

The project's first phase has aimed at building an intelligent LED infrastructure system enabled for open collaboration with device manufacturers. The project has been an extension of LED iBond's patented light technology called TRACY being a modular lamp concept. The project aimed at extending the capabilities in intelligent lighting, with a dual-purpose LED panel serving as infrastructure for click-on sensors and devices in commercial and industrial applications.

The intelligent lighting was envisioned to be based on modular light fixtures delivering the central IoT infrastructure in both new and existing buildings. Imagine installation of IoT devices such as light sensors, temperature and humidity sensors, cameras and smoke alarms, and monitoring and data collection.

Scope 1 – Findings
The project has shown that the use of Tracy as infrastructure in other than electrical supply terms has proven unfeasible. Partly due to the low bandwidth of the infrastructure based on the TRACY light panel (due to high capacitance), and partly due to expensive and complicated solution for separating data over the TRACY light panel. Moreover, the de facto industry standard today is wireless communication, which has proven more suitable for the IoT in smart buildings.

As a conclusion, the commercial attractiveness of the developed solution as envisioned in the beginning of the project was two low and a consequence the scope of the project changed to scope 2.

Despite this conclusion to change the scope, the work of scope 1 has delivered significant results that had formed the platform for the work in scope 2.

Some of the key results of Scope 1 are:

<u>Software – used for advanced light management in smart buildings:</u>

- Development of software for the LED iBond hardware Controller to operate autonomously as intelligent controller with various sensors. The software is open for wireless connected sensors of the most “standard” communication protocols.
- Software for the LED iBond Back-end (cloud service): handles all sensor data and all operative units and sensors. This is also where the programming of actions takes place depending on data received from various sensors connected to the system.

Hardware – TRACY portfolio:

- Cost reduction and upgraded LED technology (24VDC/higher efficiency)
- System components for easy adaptation to selected markets
- Simple sensor program for autonomous light control
- IP67 water and dust resistant

Scope 2 - *Tracy and Gracy hardware and software platform for energy optimization in vertical and indoor farming, by intelligent regulation of light and other growth parameters, to optimize the yield from vertical and indoor farms using artificial light.*

The project’s second phase has aimed to bring value to indoor farming by optimized lighting and intelligent regulation of such light.
LED iBond’s TRACY and GRACY lamp technology have been modified and optimized for the specific needs of various use cases in indoor farming. Such use cases are growing of, e.g., lettuces, strawberries, and cannabis. The technology has been optimized to fit the different types of technical solution used in various farms around the world. Such solutions have been containers for vanilla, towers for herbs, transportation trolleys used for green leaves, and growth light for greenhouses.

Scope 2 – Findings
Based in engagement with the industry, the project has revealed that monitoring and control of climate in today’s indoor farms and greenhouse, takes place on the scale of each section of a greenhouse complex (e.g. a section of 10x100 meters) and the control (of temperature, humidity, watering etc) is based on the individual farms historic experience. Monitoring of the plants health and quality is based in the farmer’s own inspection (feel and look). The industry is in general not data driven in any respect. The results of the project have shown that the use of lamps with the right and optimized light spectrum can increase the yield significantly (+30%) and the potential for value (energy saving or increased production with the same energy) of the advanced control of the growth environment is huge.

The project has also shown that the first generation of LED growth lamps (period 2015-22) have proven to be of low quality not last lasting long (burn out) and they provide low light homogeneity. The farmers have not seen LED as mature and >95% of all lamps in the Danish greenhouse industry are old traditional HPS lamps with low energy efficiency. The lack of good LED lamps have delayed the transition from old the HPS/natrium lamps to energy saving LED technology. However, the industry is ready for the transition once the right lamp is available on the market.

Furthermore, the project have shown that the use of low cost standard sensors (e.g. for CO2, temperature, humidity) are well suitable for large scale deployment in indoor farms if the right and application specific software becomes available.

Some of the key results of Scope 2 are:

Software – Advanced light control and data collection in indoor farms:

- Sky Fields - LED iBond's cloud solution where data from the growth phase and sensors in the grow field is store. The solution also connect external IoT data such as weather forecasts and energy prices to influence control algorithms and action taken to minimize CO2.
- Support for various sensors and camera used for in situ monitoring.

Hardware – HORTISAPER toplighting portfolio:

- Market leading toplighting solution for greenhouses.
- Toplighting solution with market leading efficiency (μmol/J), light uniformity (due to patented – pending - optic technology and design)
- Highly cost effective design" (DFM) – with the use of the absolute optimal manufacturing technologies for the entire lamp.
- Ecological-design – the product supports spare part plans – and can be totally disassembled into material fractions.
- Saving 25+% in energy compared to best Natrium lamps in the market.

Perspectives

The project has provided LED iBond with very important knowledge both from a technical and market perspective. During the project and based on customer engagement, LED iBond has evaluated the commercial attractiveness of various customer segments and required offering to become successful and competitive.

As an outcome of the project, LED iBond strongly believes that the offering of advanced LED lighting requires sophisticated software management solution to harvest the full potential of the energy saving and value of the LED lighting hardware. Moreover, LED iBond believes that application specific solutions combining highly optimized LED lights with advanced software is essential to be competitive on the global market.

The results from the project clearly indicate that there are attractive opportunities with such solutions within two specific segments:

- Indoor farming for plant and food productions
- Parking facilities (Parking garages and Solar carports)

In particularly, the Indoor farming market is attractive as the value of highly advanced software solutions can have very high value on minimizing energy usages and increase farm production.

The results of the project have led to specifical products been developed and are now being offered by LED iBond.

3. Purpose and objective until April 2022

The initial scope of the project was built on the TRACY- light panels. The vision was to utilize them as IOT infrastructure -backbone for data collection and interventions in buildings and industry. To make this happen three main areas had to be developed.

A) Tracy **Software Platform** for energy optimization and industry collaboration. This is important for achieving the entirety of environmental benefits of the Tracy panels and open for 3rd party enabled port- folio devices. View basic introduction to TRACY® IoT video here.

B) The **next generation Tracy panels** with several mechanical and electrical upgrades to enable higher energy efficiency, faster adoption, and extension of the lifetime of the installation.

C) Create an **open-source sensor development kit** for external IoT device manufacturers. LED iBond will develop a few core sensors, but the overall objective is to partner with leading manufacturers to make Tracy an open platform.

Two Main Conditions failed:

- TRACY light panels could not transport the information and become the IoT infrastructure in buildings and industry.
  - The DC powered profiles simply couldn't provide a satisfactory bandwidth. It became clear that the nature of the panels, two aluminum profiles glued together acted as a large capacitor. The longer the trace – the bigger the problem. We could only reach 1200 Baud, and only with extensive hardware additions and software on each line – and yet not comparable with wireless communication, which has become state of the art in IoT communication.

- The second condition was a widespread network of Tracy installations that could utilize this technology.
  - Despite promising market evaluations, this ambition failed due to the price level and general applicability of the Tracy panels.
  - The Tracy panels were at that time primarily distributed in the Kitchen segment, and a few other standalone applications, where the Energy optimization was reached just switching to LED lightening.

However, the energetic striving to find markets and adopt applications led to several solutions that gradually have become a part of Led bond's product offering – and to a substantial extent fulfilled the objectives in the initial project formulation.

- We have upgraded the entire Tracy product line to 24VDC, now able to create traces more than 100m long - and carrying double the power. (WP3, WP6)
- We have added vital system components that make the product family more widely applicable, and attractive to a few interesting market segments. (WP3)
- We have developed a light management system for these market segments - that can work on either cabled sensor signals or wireless signals and thereby become “*a wired and a wireless infrastructure*” in the selected applications. (WP 2, WP4)
- We have significantly reduced the cost of our designs - which now makes us competitive in relation to similar solutions available on the market. (WP3)
- We are currently selling and winning contracts within the carport industry where our products fit in together with sun power panels on the roof of Carports (WP2, WP3, WP4)
- And finally, we have applied sensor systems available on the market to work with a Tracy installation in either a simple or an "integrated light management system."
- In the heart of these solution lies LED iBond’s new: Light management platform (Proprietary hardware, Software and Intuitive User interface) that we have also taken with us into the horticulture market. In the heart of these solution lies LED iBond’s new opportunity: Light management platform (Proprietary hardware, Software and Intuitive User interface) that we have also taken with us into the horticulture market. (WP1,WP2,WP4,WP6)

Beside these developments, a large number of solutions were developed and prototyped before they were stopped, this is described in chapter 7 together with the more successful developments.

4. Adjusted purpose (April 2022) November 2022 - November 2023

In the spring 2022 LED iBond decided to end the cooperation with our partners in the project, and to focus more on the horticulture industry (indoor faming).
At that time, LED iBond had several projects in the horticulture industry, that built on EUDP results (Scope 1), and opened the opportunity for an array of energy optimizations within the horticulture industry – more precisely indoor farming.

Three projects have had significant impact on the way we have refocused our objectives under the umbrella of the EUDP project:

- UNITROLL is a standard trailer used for transporting plants and herbs in the retail industry and within the catering industry. This trailer was “Transformed to a local farming trolley for herbs and green leaves".

  The business idea was energy saving (reduced waste):
    - Saving energy for transportation.
    - Local growing and distribution
    - The entrepreneur will provide the trolley with grow-media and seeds – just add water and power.

  LED iBonds contribution was super slim light design and light spectrums designed for the different crop type.LED iBond’s contribution was super slim light design and light spectrums designed for the different crop type.
  And a light control system on a pre-defined recipe (with the potential to control all relevant growing conditions based on the recipe).

- Refarmed ApS (a 10 leveled 350m2 vertical farm, that was built back in 2021) The light solution provided by another LED manufacturer could not produce the yield and product quality that was requested.

    - LED iBond made our first adjustable light spectrums for Refarmed, with a built in “local ventilation” system - as the system also suffered from high temperatures and humidity.
    - The spectrum adaptability, the light-uniformity and the light recipe idea was implemented to control the light developed for this application. First as a small test area – secondly: LED iBond ended up investing in one layer of this vertical farm as proof of concept - with the expectance of selling the reminding 9 layers.

First as a small test area – secondly: LED iBond ended up investing in one layer of this vertical farm as proof of concept - with the expectance of selling lamps for the reminding 9 layers.

Here LED iBond first saw the full value of:
- Light uniformity (increased yield and quality for less electricity cost)
- Light recipe (LED iBond could reduce the light intensity in the different growth phases without any sign of yield drop)
- Various spectra for different growth phases (LED iBond could see the clear benefit of using different spectrums for the different growth phases) Genom response on light spectrums and intensity other than photosynthesis.

- Nordic Harvest A/S (Danish company) was also interested in our new flat and highly effective light panels.
  Nordic Harvest first request was a flat design light panel with white leds only – “to resemble sun light”. But the test rapidly showed that white light did not give either yield or quality on the same level as designed spectrums.
- After the results from our results from Refarm, LED iBondRefarmed we developed 4+1 different spectrums, based on our own experience, scientific papers and customer requests. Nordic Harvest made a full comparative test with three of the first five spectrums LED iBond had developed.
  - Four different crops under three different light spectrums

This was the turning point for our project ambitions.

Reformulated Objectives (scope 2):

Tracy and Gracy **hardware and software platform for energy optimization in vertical and indoor farming**, by intelligent regulation of light and other growth parameters, to optimize the yield from vertical and indoor farms using artificial light.

The **next generation of led panels** with mechanical and electrical upgrades to enable higher energy efficiency, power supply and support of sensors, faster adoption (exchange of existing light), and increased lifetime of the installation.

Create an **open data platform** for partners to develop algorithms and control systems to further increase yield pr. energy unit.

5. Project objectives

5.1. *What was the objective of the project?*

ORIGINAL SCOPE	Re-FOCUSSED SCOPE
Tracy Software Platform for energy optimization and industry collaboration. This is important for achieving the entirety of environmental benefits of the Tracy panels and opens up for 3rd party enabled port- folio devices. View basic introduction to TRACY® IoT video here.	Hardware and software platform for energy and resource optimization in vertical and indoor farming, by intelligent regulation of light and other growth parameters, to optimize the yield from vertical and indoor farms using artificial light.
The next generation Tracy panels with several mechanical and electrical upgrades to enable higher energy efficiency, faster adoption, and extension of the lifetime of the installation.	The next generation of LED panels with mechanical and electrical upgrades to enable higher energy efficiency. Monitoring and later automatic control the system to enable higher energy efficiency.
Create an open-source sensor development kit for external IoT device manufacturers. LED iBond will develop a few core sensors, but the overall objective is to partner with leading manufacturers to make Tracy an open platform.	Create an open data platform for partners to develop and test algorithms and control systems, to further increase yield pr. energy unit.

5.2. *Which energy technology has been developed and demonstrated?*

The project has led us through several technologies to obtain the energy savings that LED iBond were looking for.

- 2. Generation of Led lightening products with focus on supreme efficiency, control, and light distribution.
  a. Termic conditions of LED for increased lifetime and efficiency
  b. Optic light control – for best possible utilization of light emitted from Leds.
  c. Best rated LEDs based on built in environment.
- Horticulture Led Lightning solutions with spectra optimization for various cultivars leading to increased yield and quality with less power.
  d. Designing Light spectrum based on available Leds, type of cultivar, and life stage – combined with preferred genome plant response.

- Intelligent lightning control for public areas
    e. Dali based control system with wired and wireless communication.
    f. IoT control and management of light solutions
    g. User interface (software) for light planning, installation, commissioning, programming service and maintenance.
- Intelligent lightning control for public areas as well as green houses and vertical farms.

    h. User interface Horticulture
    i.
- Sensor technology

6. Project implementation

6.1. *How did the project evolve?*

The project has had three phases with change in focus:

A) According to plan:
    a. Partners set off individually in the directions described in the work packages.
    b. It becomes clear that the vision cannot be completed.
B) Stop and set new targets:
    a. To what extend can the original target still be fulfilled
    b. What did LED iBond learn from tasks performed and Customer/market knowledge

The horticulture market stands out as large, with a burning platform, insufficient solutions, facing a shift in technology – and LED iBond have solutions that can be adopted to this market.

C) Reformulation of project and organization towards horticulture solutions.
    a. Change in scope
    b. Stop involvement of not contributing partners
    c. Reformulation of task
    d. Updated budget and time schedule
    e. After approval by EUDP, board key employees in especial software and Hardware development.

6.2. *Describe the risks associated with the project.*

Technology Risk:

- It became obvious that the technology risk in using Tracy as IoT backbone appeared to be a problem.

Communication Risk:

- In the first part of the project, there was too little communication between partners and teams working on individual tasks without a holistic overview. This has led to a series of results that never have been implemented and solutions that do not contribute to the overall goal.

Scope Creep:

- Scope creep often appears when no clear again goal or vision is communicated, and when teams do not communicate. LED iBond have unfortunately not been good enough to prevent his from happening in the early part of this project.

Cost risk:

- It became apparent that cost was not a new problem but was buried in the design. LED iBond have to some extent overcome this problem by redesigning major parts and components during the duration of the project.
- The new product Hortisaber is targeted to fit into the market price level – and it does so!

Operational risk:

- Especially delivery time from our subcontractors has been an issue, delaying the process and time schedule.
- But also our test sites have caused delays – that with closer communication could have been foreseen.

Health and safety risk:
LED iBond have suffered from a large number of health (sickness) -related project challenges

- Name1, former project manager, has not been active in the project since January 2022
- Name2, project manager (left the company September 2021 (April2022))
- Name3, project manager (left the company January 2022)

Skills Resource risk:

- When LED iBond got the approval for the revised project focus in November 2022, the organization was minimized, and LED iBond had to engage new resources to full fill the project. – they did not come on board before January 2022

Performance Risk:

- To perform according to plan was the overall problem with a project that has character if a scrum project rather than a housebuilding project. But the last year especially has been focused on the overall goal – and largely achieved the desired results.

Market Risk:

- It became clear over the duration of the last 1½ year that the market was in other areas of building and industry, compared to the initial vision. This is also why a new focus was sought in April-June 2022 with a focus on horticulture industry.

6.3. *Did the implementation develop as foreseen and according to milestones agreed upon?*

Despite the extra 1.5 month LED iBond asked for recently, LED iBond did not achieve all our goals. LED iBond have marked them in the Gant chart and with a little description about the work package below.

2022												2023											
	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
WP1 new: Backend development for process data																							
Task 1.1: Spec and setup database to capture plant life data																							
Task 1.2: API development to capture information and convey data to perifer elements																							
Task 1.3: Frontend development, to present plant life data																							
Task 1.4: Test and refine with VF partners																							
WP2 Monitoring and control software platform																							
Task 2.1: Discovery project to collect VF-user needs																							
Task 2.2: Design minimal viable product (MVP) requirements with technical specifications																							
Task 2.3: Development of software platform																							
Task 2.4: Interaction Guide for 3rd party interaction with ressource data																							
Task 2.5: QA testing																							
WP3 Tracy scalability enhancements, all completed in initial scope																							
WP4 Digital surveillance pf Plant life																							
Task 4.1: Define relevant sensors and Camaras to capture relevant plant life data																							
Task 4.2: Design interface to data warehouse and "built" sensors into the layout of the Vertical Farm.																							
Task 4.3: Layout logistic structure QR + interaction with Moving gutter positioning																							
WP5 Formidle resultat																							
Task 5.1: Provide presentations to relevant symposiums/trade fairs																							
Task 5.2: Invite for collaboration on our web-site																							
Task 5.3: Participate in relevant international VF-specific network																							
WP6B Layout VF-light and sensor structure for capturing data in plant life																							
TASK 6B.1 Therory and physical layout, manufacture and test VF-light panels for continous optimization																							
TASK 6B.2 Design mechanical system to move cameras over grow area to collect vital lifetime picture and imfra red picture documentation of growth																							
TASK 6B.3 Built full layer: Can be tower solutions, VF moving Gutter system og Still bay systems.																							
TASK 6B.4 Documentation from system and system conclusions																							
WP7 Project Management																							
Task 7.1: Management of the project, incl. risk management																							
Task 7.2: EUDP reporting (progress and finance)																							
New Technical milestones																							
M1 Database ready to receive data from VF-line														M1									
M2 App or Web-app userinterface to present Plant Life data																	M2						
M3 Market prone VF light panel with control system ready to launch																			M3				
M4 Logistic layout ready to recieve information															M4								
M5 Camara solution taking pictures of entire Gro layer First full production cycle with data gathering and read out of plant life																		M5					
M6 First full production cycle with data gathering and read out of plant life																		M6					
Commercial milestones																							
CM1 Signed pilot project with 2 VFs												CM1											
CM2 Accept presentation for VF conference and VF knowledge hubs																			CM2				
CM3 Final project report documenting project results																			CM3				

Figure 2: Latest communicated Gant chart – with present status

1. WP1 Backend development for process data

Modified objectives

Provide a database with access to data from all relevant parts of the VF control systems, as well as relevant sensors and cameras. Main objective is monitoring data from the "plants life cycle" in the vertical farming process.

Description of work, Modified

Task 1.1: Backend development
Specify and set up the database to capture program data as actual data and picture documentation from the plants life cycle (done)

Task 1.2: API development (application program interface)
Built or utilize APIs to secure contact to as well system info as data and cameras specified for the task (done internal demo)

Task 1.3: Frontend development
Develop GUI to present and to intervene in the process based on real time and historic "plant life data". (not done – we need more experience from responsible gardeners, in process)
Task 1.4: QA testing
Test and refine with customers/VF partners (not done)

Deliverables

D 1.1. Database and database structure optimized for real time data access (done)

D 1.2. App or Web-app user interface to present Plant Life data to analyse, and register process interventions (not done – but in process)

WP2 Monitoring and control software platform

Modified objectives

The objective is to deliver a software platform to improve energy efficiencies through intelligent monitoring and control of lights and other system components, with respect to sunlight, climate, plant health and demand variations (slow down and speed up production relative to market fluctuations).
Description of work, Modified

Task 2.1: Discovery project with customers (done)
This task stays as it is but will be closely related to WP 1: as the user needs are prerequisite to all the tasks, we are doing

Task 2.2: Design minimal viable product (MVP) requirements (done)
This also relates to WP 1 and is some of the work that has been performed in the initial phase of the EUDP project.

Task 2.3: Development of software platform (done)
Model software platform and modularize the input structure for easy access of new components - different setups etc.

Task 2.4: Plug-in capability for 3rd party developers (not done)
User guide about how to give input to the system: system data API as well as resource consumption algorithms

Task 2.5: QA testing
Test and verify individual components as well as entire platform (in process)
Deliverables

D2.1 new software platform release (done – software releases can be implemented on all running components remotely)
D2.2 new 3rd party integration manual (Not done yet)

WP3 Tracy scalability enhancements, all completed in initial scope

WP4 Digital surveillance of plant life
Modified objectives WP4
New objectives: Select relevant sensors and cameras for meaningful documentation of the plants life and decide on where and how to obtain necessary and sufficient data.

Description of work
Task 4.1: Complete prototype and verify user needs (done)
We will use the sensors and cameras to take relevant data in a not automated way to verify needs

Task 4.2: Design interface to data warehouse and "built" sensors into the layout of the Vertical Farm. (done)

Task 4.3: Layout logistic structure QR + interaction with Moving gutter positioning (Not completed yet)
Deliverables

D4.1: Functioning Prototype (done)

WP5 Sharing knowledge and opt for collaboration
Modified objectives
Present the project findings in relevant fairs and symposiums, and invite for forward collaboration

New work description
Task 5.1: Provide presentations to relevant symposiums/trade fairs (done – will be more shortly)

Task 5.2: Invite for collaboration on our web-site (done once – very little attendance – we will do movies on our website instead)

Task 5.3: Participate in relevant international VF-specific network (done)

Deliverables

D 5.1: Presentation ready for presentation (done)

D 5.2: Do the presentation (done, will be extended in the future)

WP6B Logistic system for plant life surveillance
Completely new objectives – all initial activities have been completed
Lay out a full concept for logistic system and operation of a vital component "the camera" (as digitalisation of the visual inspection is a core functionality in the system)
Optimize light panels based on feedback from VF operators and collected data

TASK 6B.1
Redefining the VF-light panel: (done)
Theory, physical layout, manufacturability, and growth tests high efficiency VF-light panels.

TASK 6B.2
Design (mechanical) system to move cameras over the entire grow area to collect vital plan life cycle documentation (leaf temperature measurements)
(principal solution developed – but not implemented)

TASK 6B.3
Built full layer of VF light: Can be tower solutions, VF moving Gutter system or Still bay systems. (only test areas done)

TASK 6B.4
Documentation from system and system conclusions (done)

D 6B.1
Operating Layer with plant life data system, live! (only operating in our rack system, will be moved out to test site when our multisensory is ready)

6.4. *Did the project experience problems not expected?*

We ended up with a very compressed scheduled at the end and were delayed due to longer component delivery times – the nature of project risk.

Also scope creep has played a role – as the products and solutions were presented to the market – we had vital input that we wanted to incorporate in the first version – to keep our perfect market fit.

7. Project results

7.1. *Was the original objective of the project obtained? If not, explain which obstacles caused it and which changes were made to the project plan to mitigate the obstacle.*

Even though the development route has been bumpy and with obstacles, the **initial objectives have also** been largely achieved.

Objective 1: Develop Tracy Software for energy optimization and 3rd party development:

Hardware:

- We have developed the LED iBond Controller and a LED iBond Master (Backend) – both have been sold and will be installed in Horticulture as well as industry in 2023 for parking facility)

Software:

- Software for the LED iBond Controller to operate autonomously as Dali Master and as well as intelligent controller with Dali sensors.
- The software is open for wireless connected sensors of the most “standard” communication protocols”.
- Software for the LED iBond Backend handles all sensor data and all operative units (Dali drivers) This is also where the programming of actions takes place (describe the broker solution)

A suite of algorithms for energy optimization:

- Basic on off control – that can be connected to existing FMS in buildings or climate computers in Horticulture.
- Sensor operated control from either “daylight harvest sensors, Pir and Microware presence detection – or clock operation.
- Sensors in test in Horticulture: Light sensors, humidity, temperature, CO2, Soil humidity, O2 in soil, Leaf temperature
- IoT: Weather forecasts, Energy prices, Data collection for AI optimization

GUI for LED iBond Lightning Control:

- Gui that work as design process as well as control in the same application – with an intuitive interface.

Objective 2: Tracy scalability development to enable higher energy efficiency and faster adoption.

TRACY product family:

- Cost reduction and upgraded LED technology.
- 24VDC for more reach and higher efficiency
- System components for easy adaptation to selected markets.
- Simple sensor program for autonomous light control

Gracy Family:

- Cost reduction upgraded LED technology.
- 24VDC technology for single side processing of ACP
- System components for selected markets

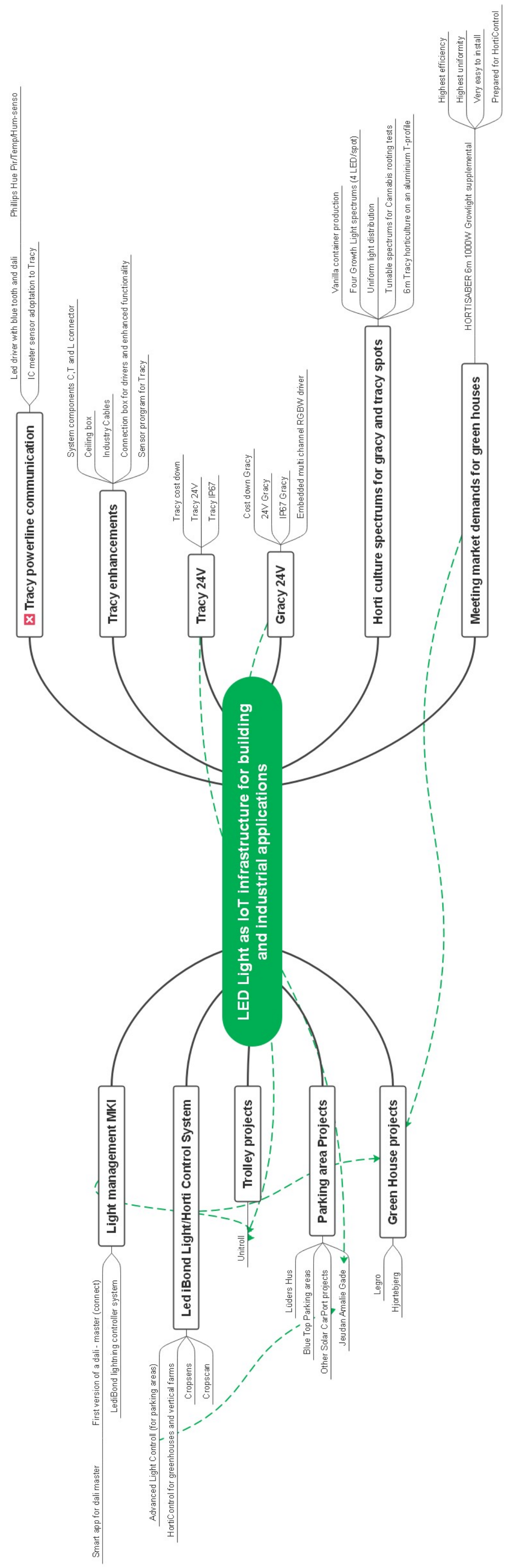
- Sensor system for Industry solutions

Hortisaber:
- Market leading efficiency µmol/J (recognized supplier)
- Market leading uniformity – due to patented optic technology
- "Cost effective design" – we use the absolute optimal manufacturing technologies for the entire lamp.
- E-design – the product supports spare part plant – and total disassembly in material fractions.
- Saving 25% in energy compared to the best Natrium lamps in the marked.
- Having significantly higher uniformity and efficiency than comparable LED products
- The product is developed in dialogue with market leading implementation company ensuring fast and easy installations.

Objective 3: Develop Open-source sensor development kit for external IoT device manufacturers.
- We did not provide an open-source development kit, but we offer full adoption of known communication protocols in our Hardware and software solutions.

7.2. *Describe the obtained technological results. Did the project produce results not expected?*

We have enclosed a map showing the results created during the project.



LED Light as IoT infrastructure for building and industrial applications
Tracy powerline communication
Led driver with blue tooth and dali
Phillips Hue Pir/Temp/Hum-senso
IC meter sensor adoptation to Tracy
Tracy enhancements
System components C,T and L connector
Ceiling box
Industry Cables
Connection box for drivers and enhanced functionality
Sensor program for Tracy
Tracy 24V
Tracy cost down
Tracy 24V
Tracy IP67
Gracy 24V
Cost down Gracy
24V Gracy
IP67 Gracy
Embedded multi channel RGBW driver
Horti culture spectrums for gracy and tracy spots
Vanilla container production
Four Growth Light spectrums (4 LED/spot)
Uniform light distribution
Tunable spectrums for Cannabis rooting tests
6m Tracy horticulture on an aluminium T-profile
Meeting market demands for green houses
HORTISABER 6m 1000W Growlight supplemental
Highest efficiency
Highest uniformity
Very easy to install
Prepared for HortiControl
Light management MKI
Smart app for dali master
First version of a dali - master (connect)
LedBond lightning controller system
Led iBond Light/Horti Control System
Advanced Light Controll (for parking areas)
HortiControl for greenhouses and vertical farms
Cropsens
Cropscan
Trolley projects
Unitroll
Parking area Projects
Lüders Hus
Blue Top Parking areas
Other Solar CarPort projects
Jeudan Amalie Gade
Green House projects
Legro
Hjortebjerg

7.2.1. Figure Mindmap with created and demonstrated solutions. Tracy Power Line Communication

In order to communicate over the Tracy Panels, we designed and tested circuitry to both communicate and receive data through Tracy. Due to the very high capacitance on Tracy (caused by the way it is designed and produced by gluing two aluminum pieces together) it was only possible to get a data throughput around 1200baud. Quite low when comparing to low power small device communicating wireless at a much higher speed.
Also the circuitry on each LED spot (the PCB) would be very challenging to fit. Due to those challenges and the low communication rate this project was not feasible and therefore stopped.

7.2.2. Tracy special LED Driver with Bluetooth and DALI communication

Special purpose to Power Tracy with 12V when LEDs in ON mode and 8V for LEDs in Off mode, this maintains power (8V) on Tracy to support power to other devices attached to Tracy. (E.g., Smal sensors etc.) This is quite unique in the system.
There was also designed/programmed and App for iOS & Android App to facilitate the configuration of a numbers of Tracy Panels in series to the Driver. The user could control the settings of the power levels, # of LED's to be powered at what level. In daily use, it could control ON/OFF/ light dimming. The driver could also be part of a DALI Network.
This became the basis for the IoT functionality being able to attach small sensors to the Tracy Panel, that would stay powered when voltage was decreased to 8V (were LEDs would be OFF) The sensors would be wireless devices using Zig Bee or BLE communication.

Figure 3: LED iBond IoT driver - 0-Series manufactured

7.2.3. Philips HUE based PIR/Temperature/Humidity sensor.

A sensor based on Philips HUE PIR/Temperature/Humidity sensor that can connect (Click on) to Tracy. This product was designed, adding parts within the Philips HUE sensor and build the mechanics connector to attach to Tracy.

Figure 4: Philips Hue - power sourced from Tracy

7.2.4. IC-meter sensor adaption to Tracy

IC-meter (Danish company) sensor adaption to Tracy, with the purpose of delivering power to the IC-meter Environment Sensor from Tracy. Different solution to attach the Sensor in a Tracy line. The energy perspective in this sensor is a new way to distribute heating cost, based on a combination of temperature and humidity in the apartment rather than the present calorimeter readings – leading to more energy efficient behaviour.

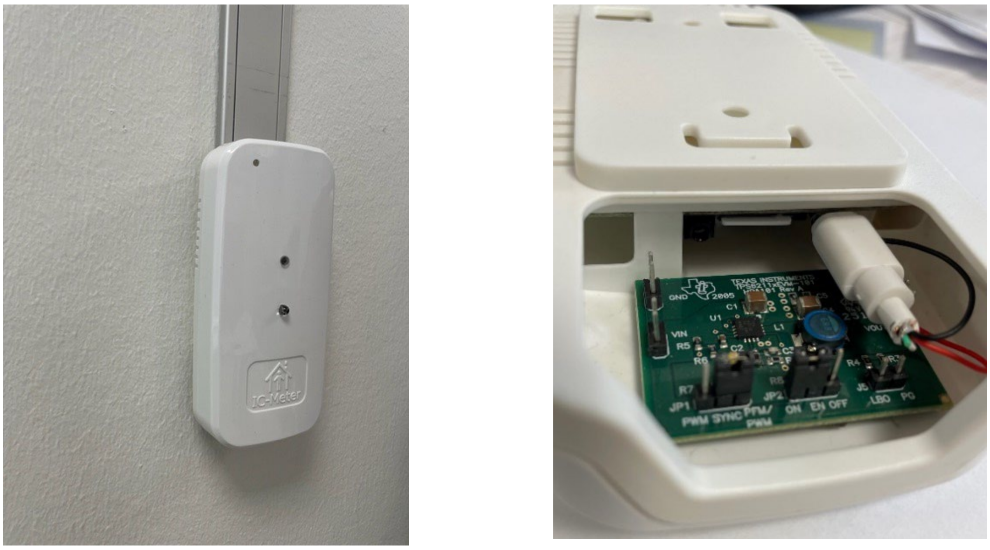


Figure 5: IC meter with power soursing in Tracy

7.2.5. Tracy system components (T-, L- and C-connectors)

Early T & L and C connector was prototyped to make Tracy to Tracy connection as an Angle horizontal or Vertical and a T connection to make a branch on the Tracy line. (Ease of use and more versatile setups)

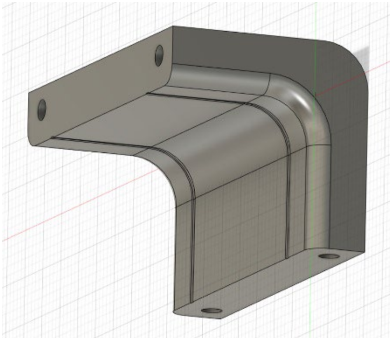


Figure 6The L connector allow for Tracy to run down from ceiling

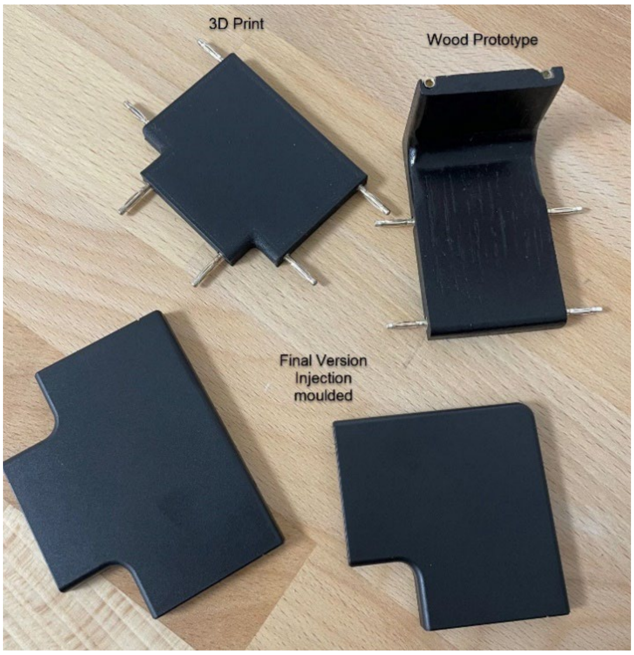


Figure 7: Final versions of the C (corner) and T-connector

7.2.6. Ceiling Box

Ceiling Box that allowed 3 branches of Tracy lines to be powered, this for easy installation along with Tracy. Ceiling Box could contain different DALI Drivers to suite the light configuration. Together with dali sensors. The product was requested from “construction Trailer” companies who wanted low energy, long lifetime light solution with automatic power off/on of light. Easy to install and easy to refurbish.

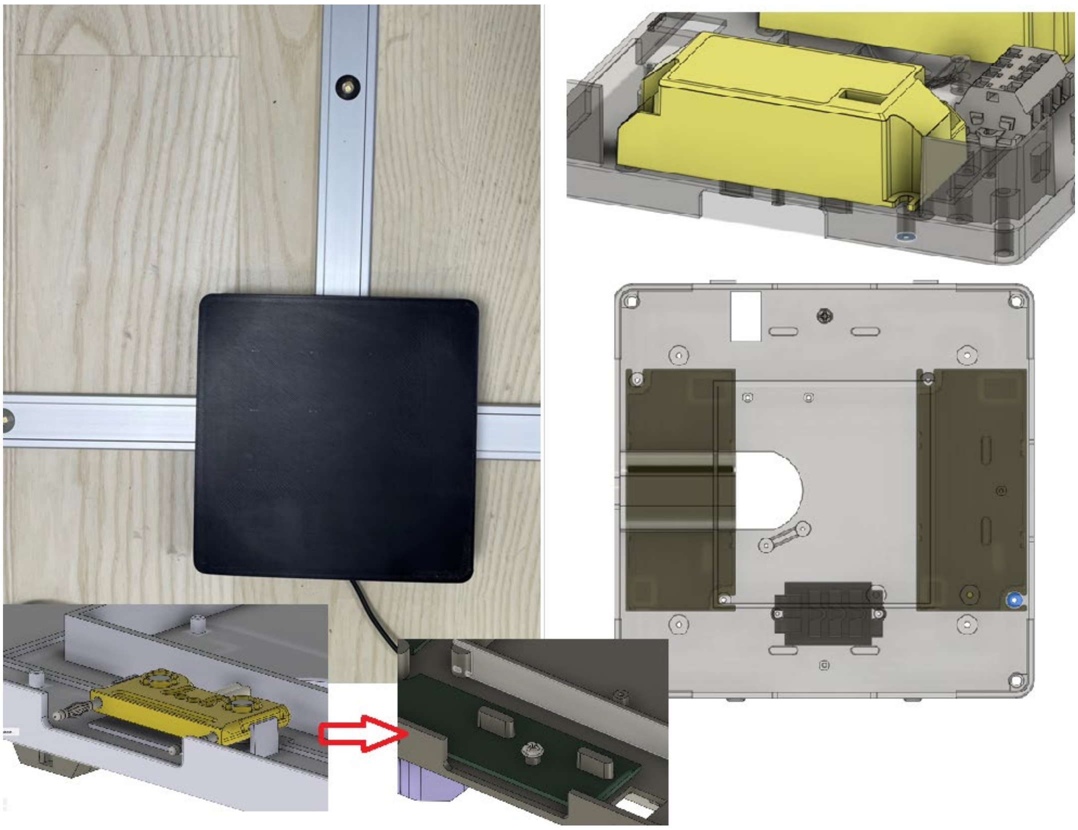


Figure 8: Ceiling box, contains driver and connections to 3 Tracy panels, design for Trailers

7.2.7. Cost down – efficiency up and wider range (Tracy 24V)

Tracy 24V family product line is based on:

- The most effective and durable JR5050 LED, increasing the efficiency with 40%
- New design of reflector (40% reduction in reflector – and better light distribution)
- IP67 design to approach outdoor environment.
- Reduced transmission loss due to higher DC Voltage
- Off the shelf driver directly applicable in as well home as in industry applicationsOff-the-shelf driver directly applicable in as well home as in industry applications

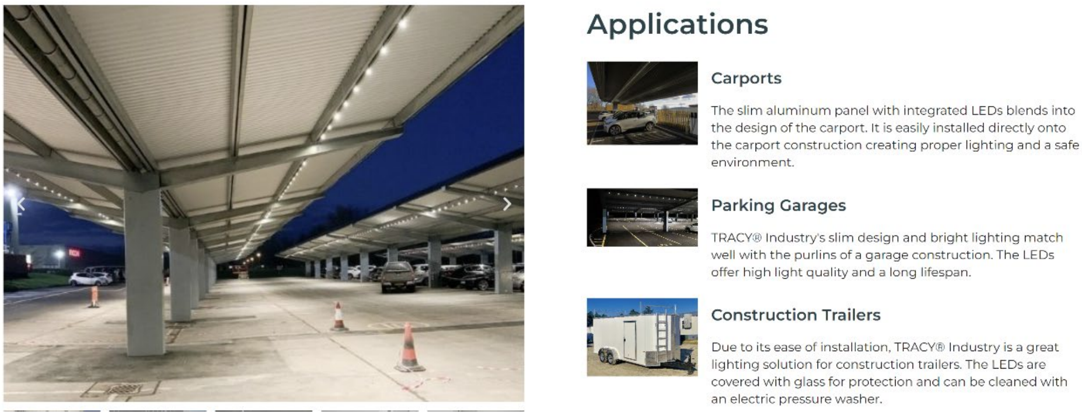


Figure 9: Tracy for solar Carports

7.2.8. Dali Master (connector) version 1

DALI Master (4 channels), the first DALI master including Firmware and SmartApp application was designed and tested in detail.
It was able to run a Light receipt for defined crops in periods and recycle the same period, along with instant change running for a predefined time with fall back to schedule. Reporting back to a backend. User login and notifications all set up with double authorization.

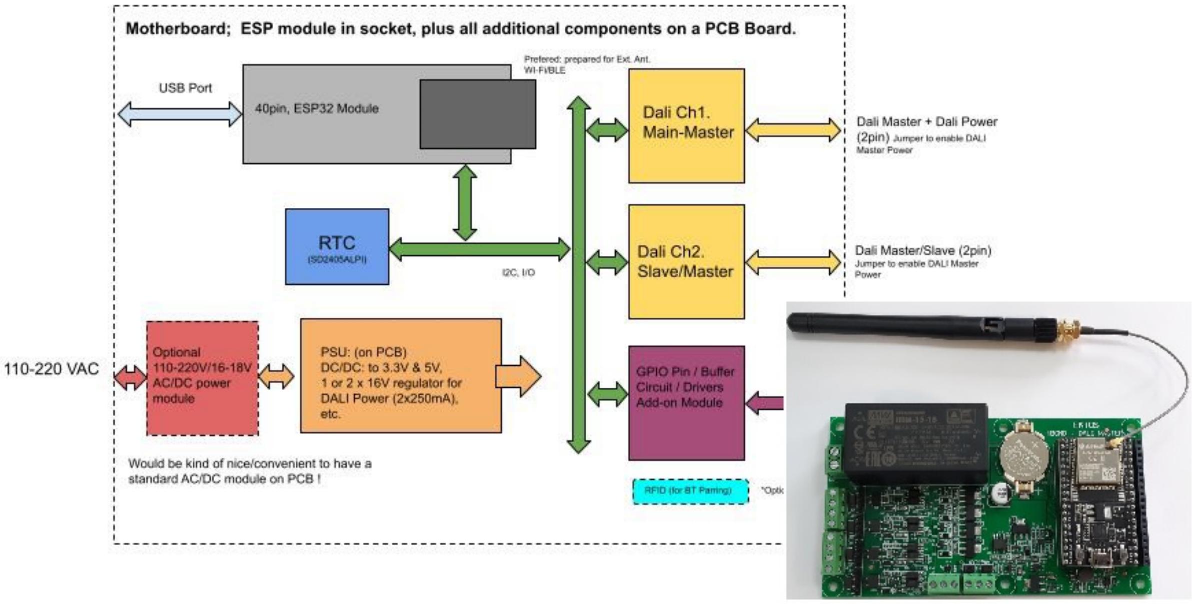


Figure 10: First version of Dali Master

Beta Unit was used to receive a recipe and control UniTroll 4 shelf Rack to grow/maintain herbs in e.g., a restaurant or a catering firm.

7.2.9. SMART App (For DALI Master)

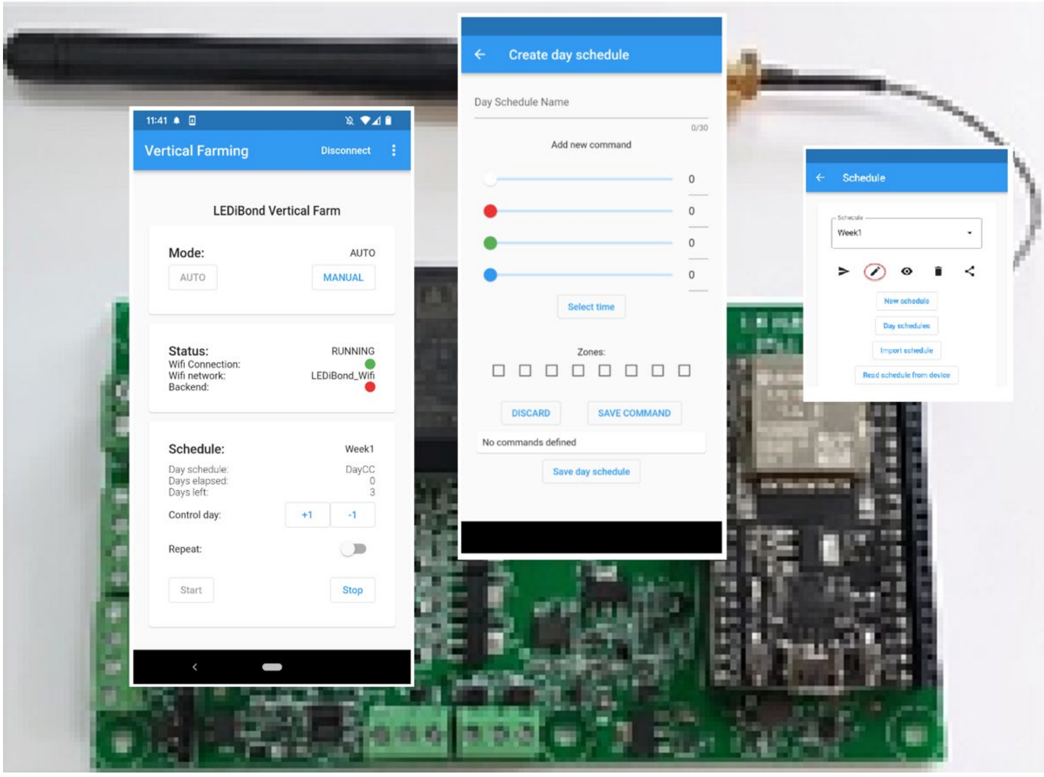


Figure 11: Dali Master APP for programming light schedules

The Beta Unit was also used at Reframed for 6 months with no failures, this unit has been the base for the next generation DALI master and backend software.

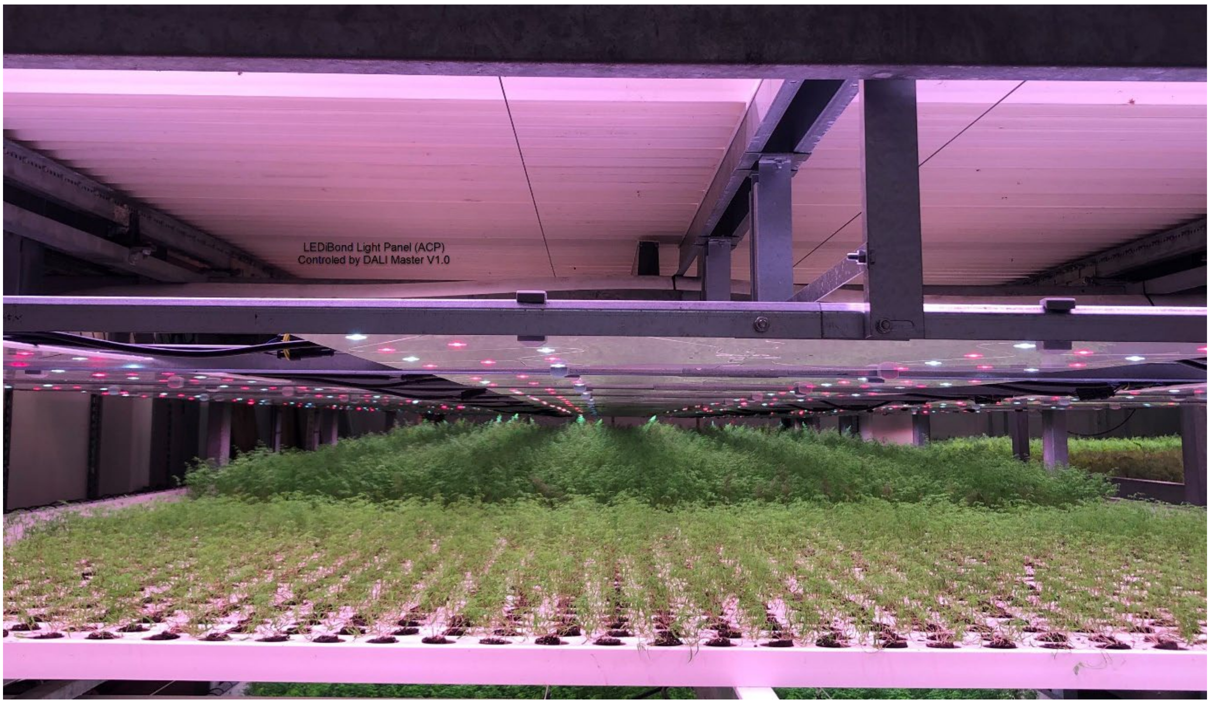


Figure 12: LED iBond light panels in Refarmed

7.2.10. Unitroll

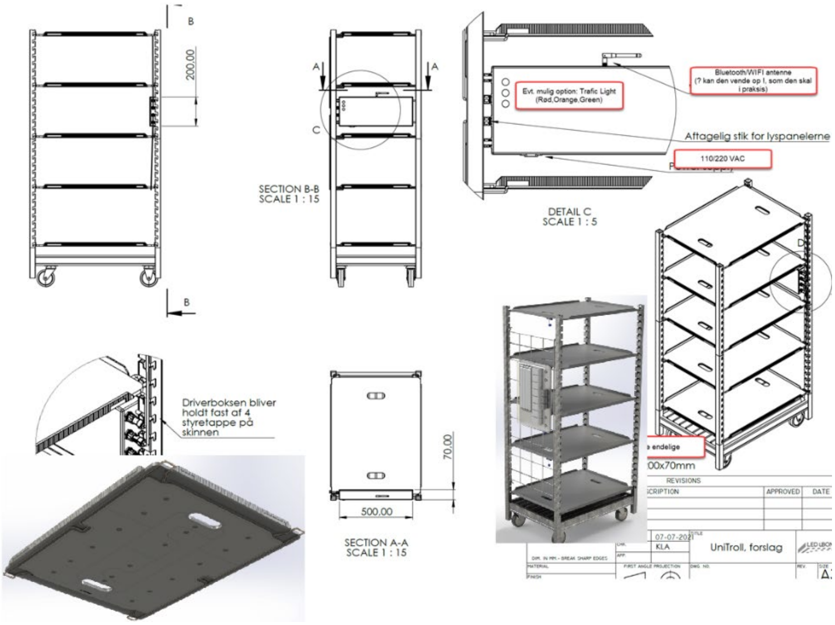
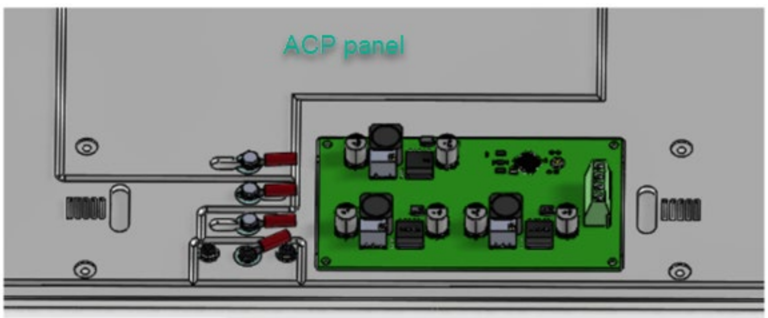
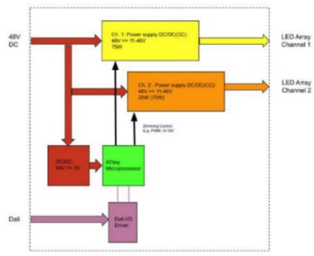


Figure 13: Unitroll foldable rack system - now with the option of growth light

For the UniTrol Rack we designed and & prototyped a successful system: Shelf with 2 Color + white LEDs in separate circuits so they could be controlled individually. Along with the DALI master version 1 was able to be a totally self-controlled system (autonomous) only needing a Power source for the LEDs and Controller. An Android App that could receive a Grow Plan from a QR code along with the delivery of the crops to be grown in the rack. E.g., a Catering or restaurant kitchen could receive prenursery herbs that they could grow and harvest when needed. The light recipe was delivered along with the crops from the delivering company.

7.2.11. Embedded multi-channel drivers for RGBW light Circuit





Embedded LED Driver for our ACP light product
Sourcing multi-channel drivers for RGBW light Circuit is expensive and you pay a lot for the enclosures multiple times also they take up a lot of space, so we worked on a concept to Power from a simple low voltage DC Source. Designed but never prototyped.

7.2.12. Working with designed light Spectrum for vanilla

Moving into the designated artificial light uncovered a whole new dimension of optimizing light for horticulture, and thereby saving energy.
As described multichannel designs with different leds: Unitroll, Refarmed and controlling leds individually to give the desired spectrum.

Tracy with designed light spectrum was first pursued in a solution for a Danish Vanilla farm start up. Here the first spot combining several leds were made.

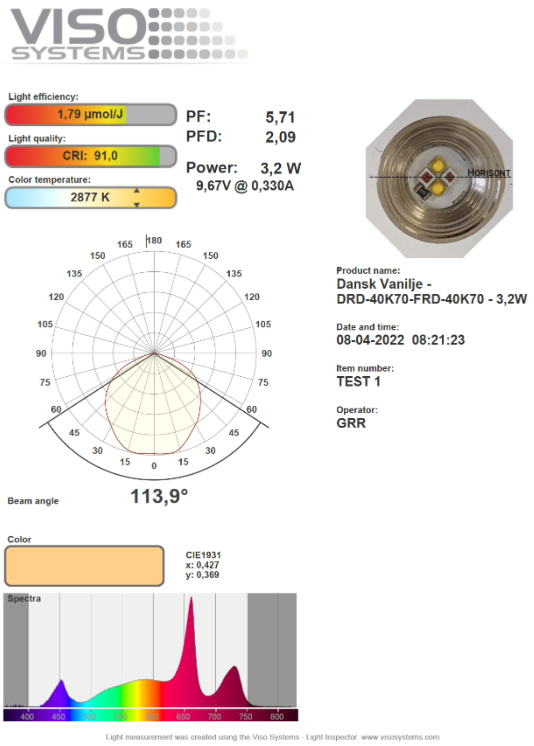


Figure 14: Tracy panels with Far Red leds for Vanilla production

From literature it was clear that different crops had different preferences of spectrums, and also vanilla "*A vanilla plant needs indirect sunlight in the morning and evening, and bright filtered shade in the afternoon.*"

7.2.13. Four grow light spectrums (maximum yield pr watt)

We were contacted by several verical/indoor farmers with different ideas about optimization of energy use in horticulture.
Mainly three different segments:

- Vertical farm projects From Japan to US
- Trom trolley or in store systems
- And Swee-Green with an instore 2-layer vertical farm

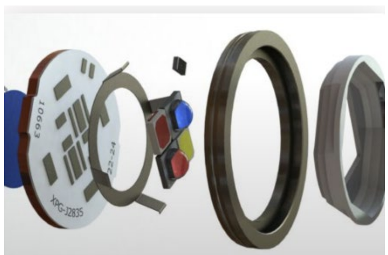


Figure 15: Spot with four high efficiency LEDs

Different requirements – depending on use case - to spectrum:

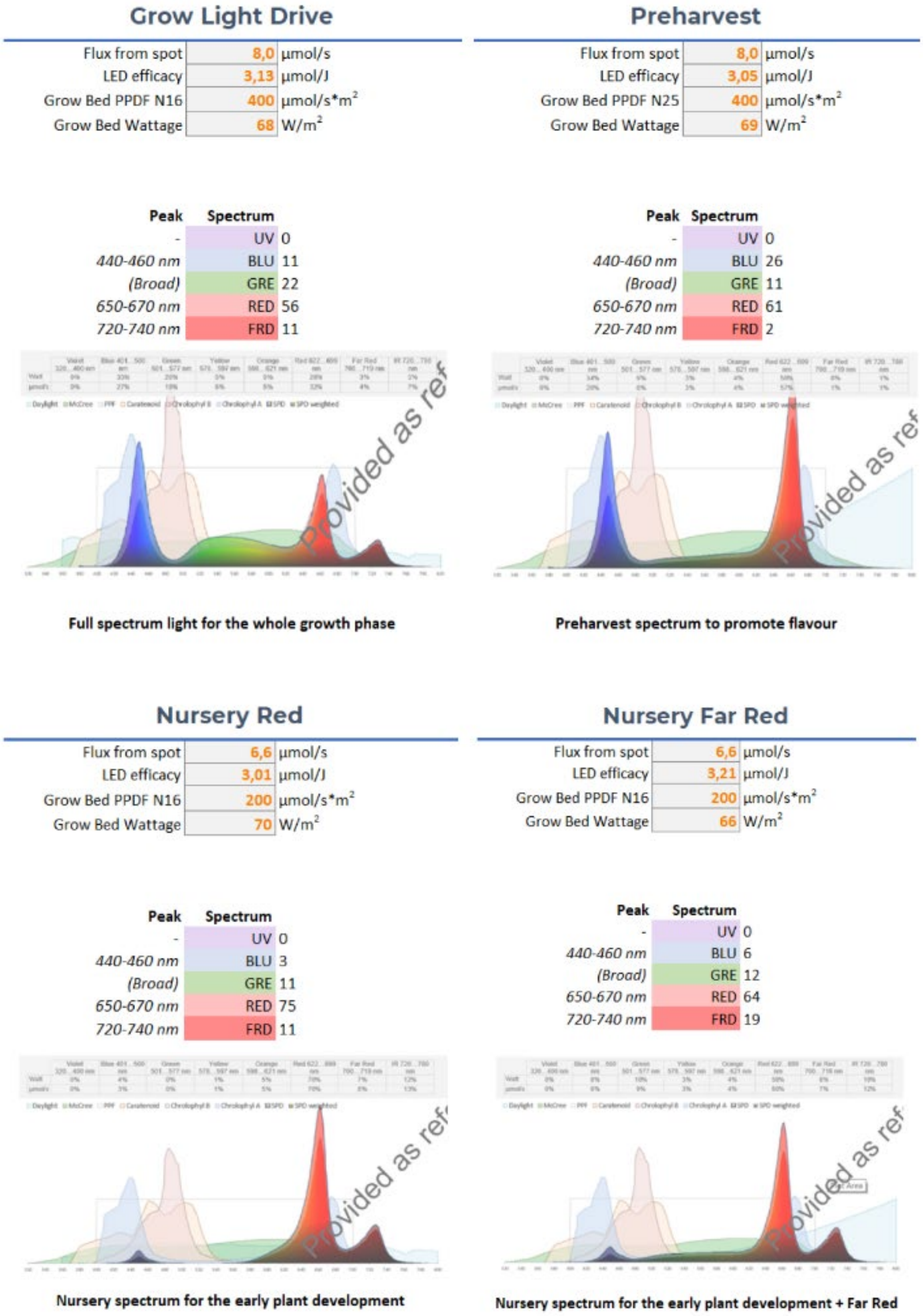


Figure 16: Four standard Spectrums for different life stages of crops

7.2.14. Uniform light distribution

From our test with Refarmed we saw that existing LED lamp providers had problems with uniform light distribution to the rim of the grow field. With our ACP solution we could freely distribute leds to reach the wished intensity, and at the same time provide a uniform light distribution covering the entire growth area.

We offered 3 types of standard 600x800 ACP panels for rim position and center position, available with 12 – 16 and 25 leds – in 5 different light spectrums.

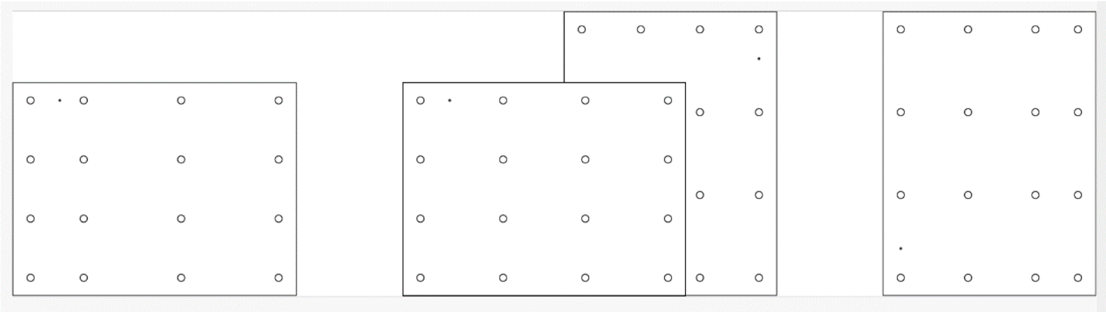


Figure 17: Standarn ACPs with different spacing of LEDs for highst possible unifomity

7.2.15. Tunable spectrums, Cannabis rooting research in Macedonia

To a wide extent our proposals for new lamps with uniformity and standard spectrums were positively received – but more as an invitation to come up with special requirements – than actually buying in quantities.
This also goes for the Macedonian Cannabis Rooting project. The requirement was to balance three spectrums to a desired output.

We made a software solution to tune a desired spectrum, in a three channel ACP solution. All controlled by a Dali control system.

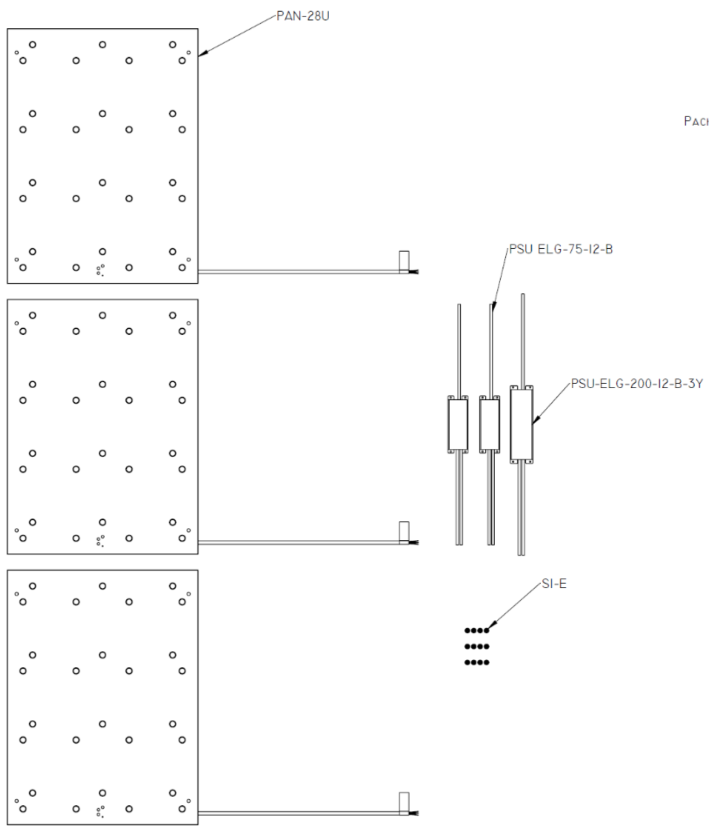
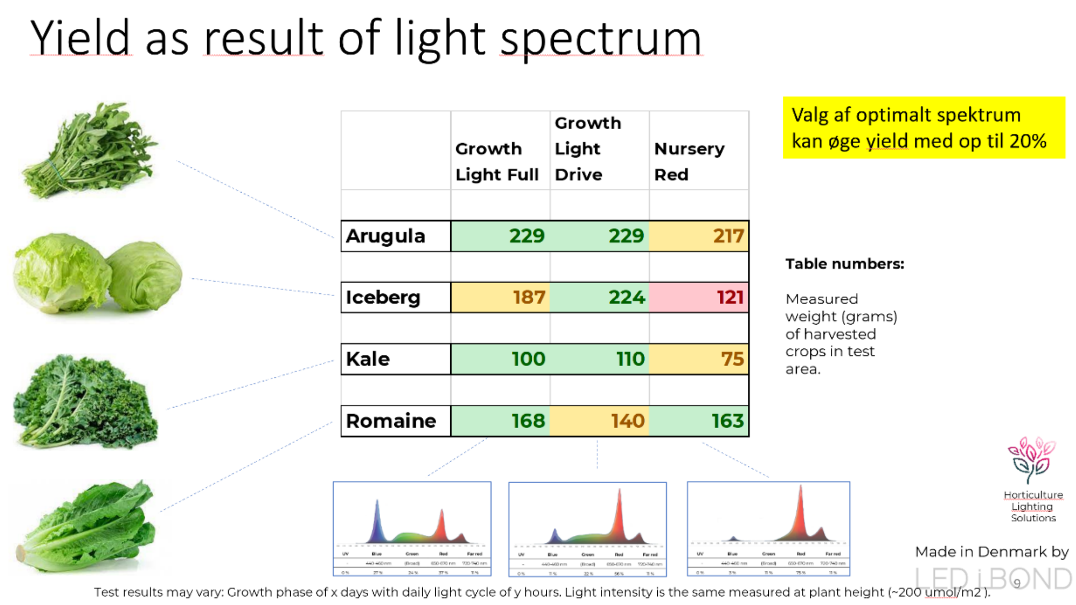


Figure 18: Three sets of multi led spots to enable large spectrum variation for test with Cannabis rooting.

7.2.16. Getting proper test results from our different spectrums

Probably the most important result in the project!
We knew from literature that spectrums matter – but how much was still relatively wage. Nordic Harvest got three different light panels with each their spectrums, Growlight Full, Grow Light Drive and Nursery Red.

Under the exact same conditions, a number of different light panels were tested with three different crops: Arugula, Iceberg, Kale and Romaine.
As seen in the illustrations there can be very large differences in yield based on spectrum – up to 85% more yield from the worst to the best spectrum. Everything else remained stable in the process. As a general comment we claim that you can achieve 20% more yield choosing the right light spectrum.



	Growth Light Full	Growth Light Drive	Nursery Red
Arugula	229	229	217
Iceberg	187	224	121
Kale	100	110	75
Romaine	168	140	163

Figure 19: Large variations in yield with different spectrums and different crops

7.2.17. Change in Horticulture strategy Autumn 2022

From Late 2021 until autumn 2022 energy-cost, yield and quality effective solutions had been provided into the “hyped vertical farming industry” – with its variants from in-shop farms to container solutions.
Leading to a number of significant findings from an energy efficiency point of view – but barely any business.

Documented findings:

- LED light with spectrums that fit with crops can reduce energy consumption with everything form 60-25%, increase yield with minimum 20% and improve quality as well.
- If light intensity and spectrums are controlled through the growth phases it will improve yield and quality relative to cost as well (plants in the first phase requires less light than later phases of its growth cycle).
- Providing high uniformity is a must – solved either by uniformity optimized light panels, or by wasting light going over the edge of the growfield. We have solutions for this as well.

We decided to pursue the supplementary light for green houses – called toplight or toplighting.

- Almost all Danish greenhouses still have old natrium lamps in their facilities that must be replaced as some point in time.
- We know that we can reduce lightning cost relative to old Natrium lamps with minimum 65% and increase yield at the same time.

- This also goes for the new natrium lamps but with approximately 40% savings using our LED lamp..
- And for all 1. generation LED lamps that do not live up to demands of uniformity or efficiency – and have not made spectrum optimization.

- AND – there is a prone market of significant size just next door.

7.2.18. Tracy Horticulture on Alu T-Profile

Our first attempt to communicate with this market was based on a 6m T-Profile with 150-180W high efficiency LEDs in our standard spectrums.

We created a high uniformity with a broad light distribution, and within four named spectrums.

But as mentioned earlier – the technology platform is simply too expensive to meet the market and TRACY could not deliver the required power pr meter.

Figure 20: Model photo of the pre-phase of hortisaber

7.2.19. HORTISABER – a complete change in LED iBond technology.

During early summer 2023 this new top light solution for greenhouses was developed.

Producing 1000W market leading efficiency grow light. Overcoming uniformity-, thermic- and pricing-issues – developed with customer and stakeholders in focus.

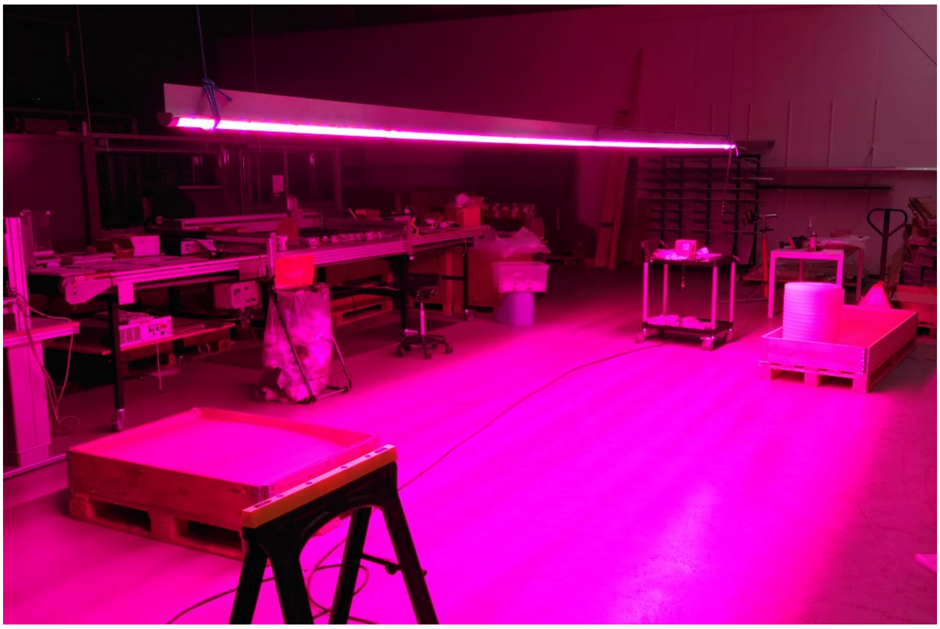


Figure 21: Hortisaber with destinct controlling of Light towards the grow-field

The important thing to observe from this picture is the optical control of the light – with very high uniformity right to the dark line.

The designed optics in the lamp redirect all the light that would have ended outside the grow field, inside the grow field.
Further the optics is leveling the flux over the entire growth area.
The longitudinal uniformity we get for free!

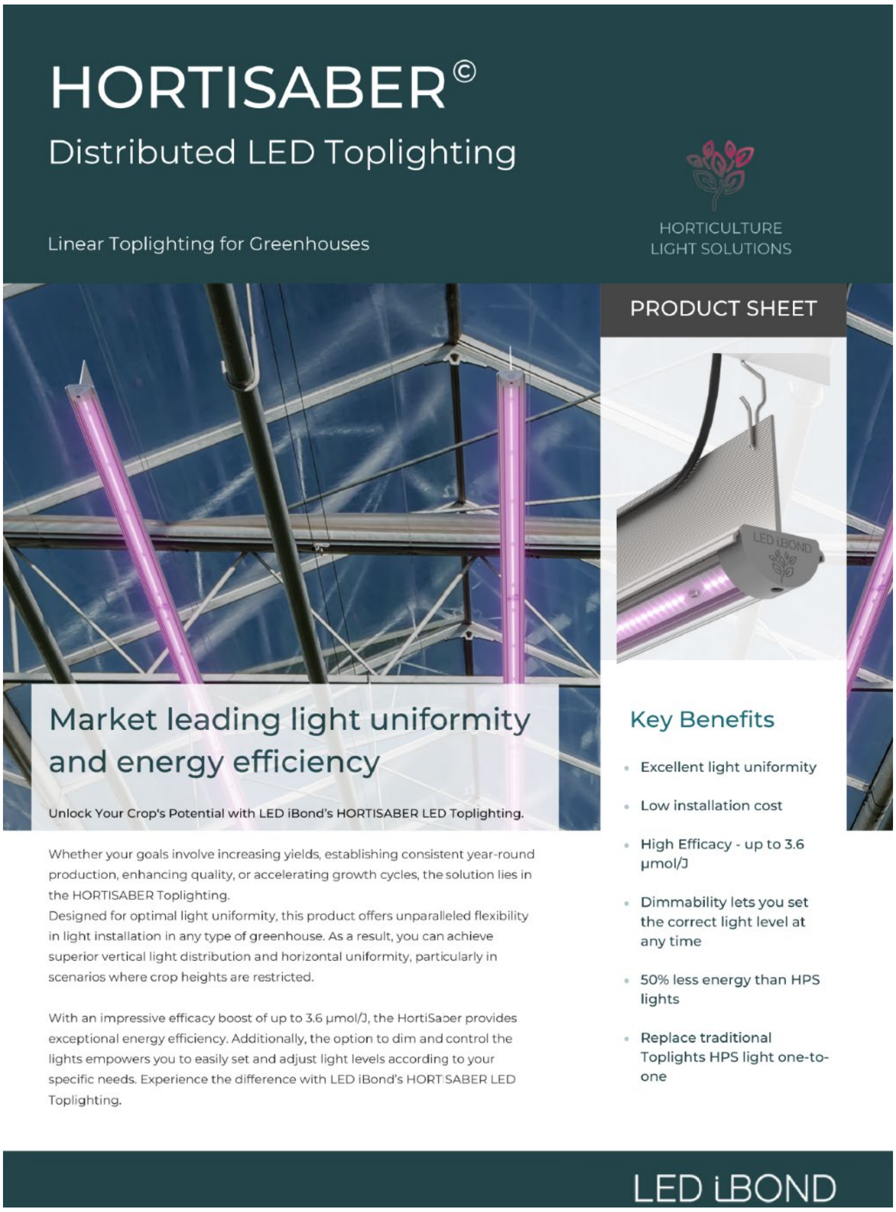
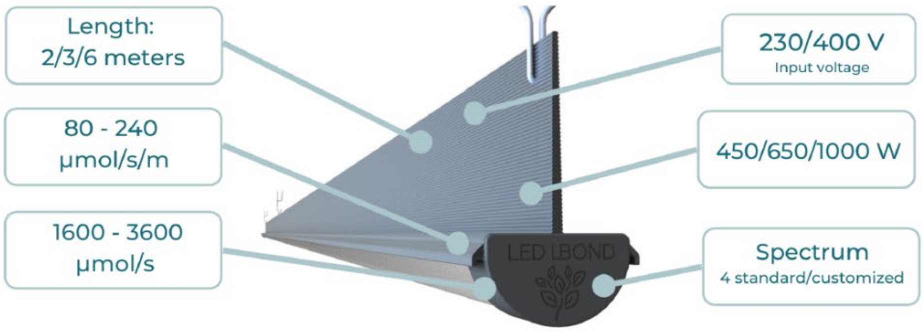


Figure 22: Early product sheet of Hortisaber

HORTISABER© Product Family

- developed with Industry Leading Greenhouse Growers



Product specifications

		HORTISABER 1000 6m	HORTISABER 650 6m	HORTISABER 450 6m
Electrical	Power supply unit	1000W	650W	450W
	Power efficiency	> 0,96 (@ min. 70% load)		
	Power Factor	0,95 - 0,98		
	Input voltage AC [V]	180 -528 VAC	180 -528 VAC	127 - 431 VAC
	Frequency	47-63 Hz		
	Dimming/control interface	0-10V or DALI-2		
	Light control system	LIB Horticore (DALI-2)		
Optical	Light output (PPF*) - [µmol/s]	3608	2360	1620
	Efficacy** - [µmol/J]	3.2 - 3.6		
	Light output density*** (PPFD*) - [µmol/s/m2]	240	150	110
	Spectrum - options	GLD, GLF, NR, PHB, customised		
Physical	Size lamp options (LxWXH) / Weight - 6 meter	600 x 7,2 x 12,3 cm / 13,2 kg		
	Size lamp (LxWXH) / Weight - 2 + 3 meters	200 x 7,2 x 12,3 cm / 4,4 kg + 300 x 7,2 x 12,3 cm / 6,6 kg		
	Size Power supply (LxWxH) cm / Weight	310 x 144 x 49 / 4,2 kg	280 x 144 x 49 / 3,9 kg	262 x 125 x 44 / 2,8 kg
	Height above crops	typical 0,6-4 meters (@2 meter spacing between rows of HORTISABER)		
General	Housing	Aluminum (Lamp panel + power supply), Acryllic lens		
	Mounting	Beam hooks + various options		
	Temperature	Operating: -10-45C, Storage: -20-70C		
	Humidity	20-95% RH non-condensing		
	Ingress Protection (IP)	Lamp: IP66, Power supply: IP67		
	Lifetime	>50.000 hours (L90)		
	Cooling	Passively - air-cooled		
	Compliance	CE, RoHS		
	Warranty	5 years - limited		

*Photosynthetic Photon Flux + Density **Value depends on selected spectrum and dimming level *** Estimated for 12 m^2 @80% per HORTISABER-6M

Figure 23: Early product and family specification of Hortisaber

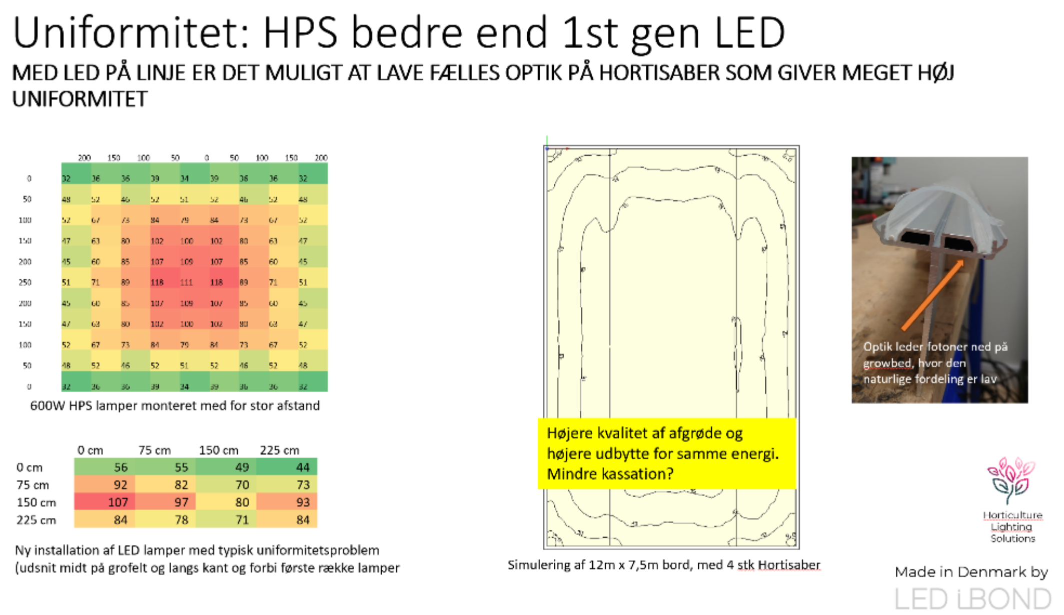


Figure 24: Especially 1. generation LED lamps have poor uniformity

7.2.20. Proof of Concept “October 2023”, LED efficiency and uniformity

A Greenhouse owner has had new lamps installed spring 2020.

- 32 pcs. Of 600W Lindpro Master Green lamps installed.
- Covering an area of 60mx10,5m
- Delivering an average of 83,4 µmol/m2s
- *Measured average 92,8 µmol/s m^2*
- Uniformity claimed: 92,1%
- *Measured Uniformity 74,3%*
- ***Consumption: 61w/m2***

Test area with Hortisaber:

6 Hortisaber lamps to cover the same area as 12,5 Lindpro master lamps

- Average: 97,6 µmol/s/m^2
- Uniformity: > 82%
- **Consumption 47W/m2**

One single Hortisaber (cross growfield uniformity

ID	PFD
4	62,48484
5	61,74126
6	57,11261
7	61,94603
8	87,26737
9	76,59207
10	87,48185
11	80,04734
12	63,05492
13	60,51446
14	66,95973
Average	69,56386
Minimum	57,11261
Maximum	87,48185
Uniformity:Emin/Eav	0,82101
Diversity:Emin/Emax	1,257576

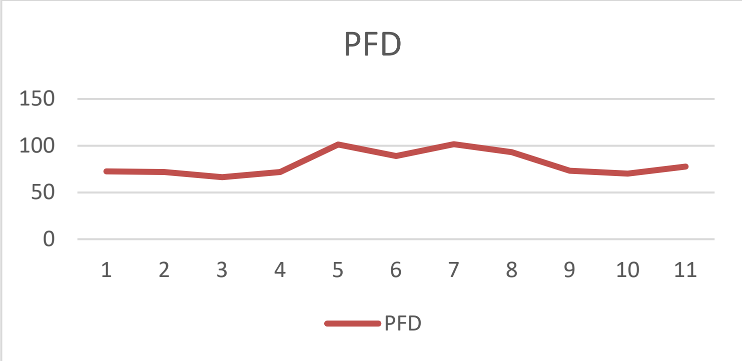


Figure 25: Uniformity was superior from the first measurements.

:

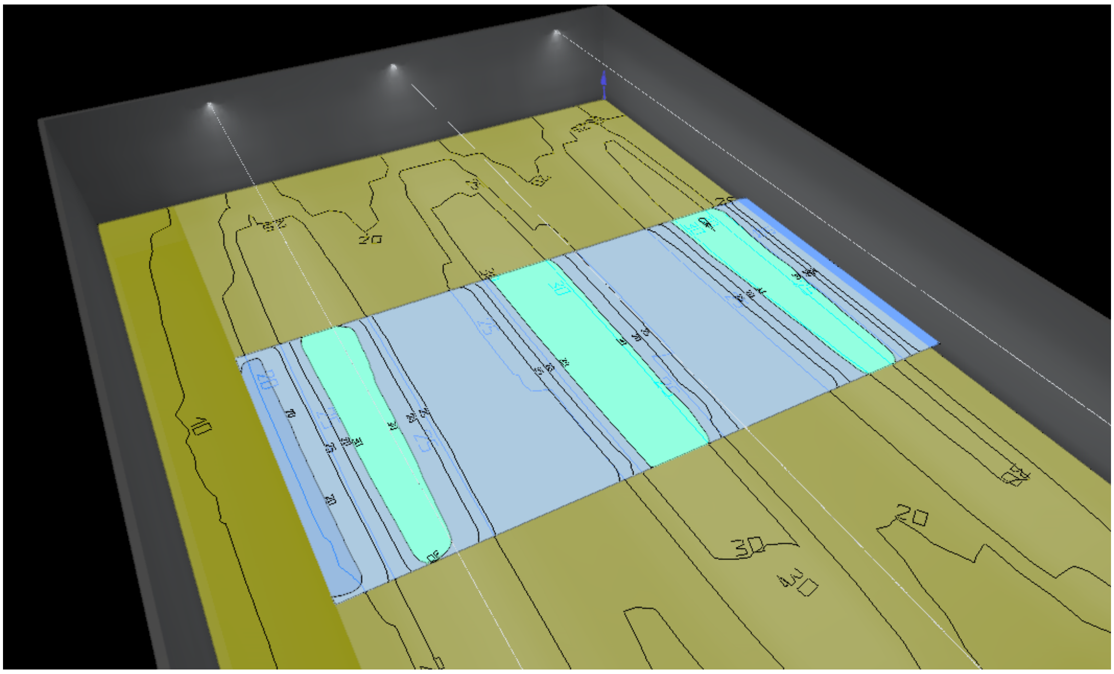


Figure 26: Dialux of hortisaber model in a three row setup

7.2.21. Hortisaber Test site LEGRO

2750	mm	1,774194	1550	mm
3750	mm		2113,636	mm
1800	mm		1014,545	mm

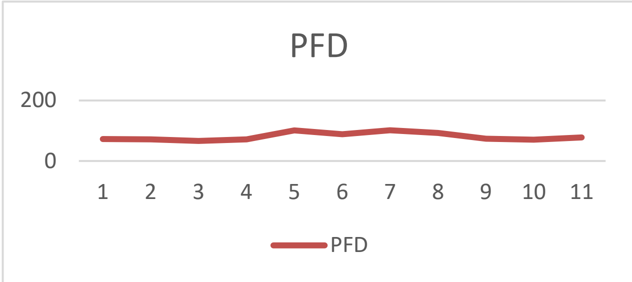


Figure 27: Size and μmol demand decides the configuration, Legro wanted a 200μmol/s/m2 solution

Figure 28: 9m single line Hortisaber in LEGRO's test area - easily provides the necessary light level

7.2.22. Hortisaber test site Hjortebjerg

2750 mm	1,774194	1550 mm
3750 mm		2113,636 mm
1800 mm		1014,545 mm

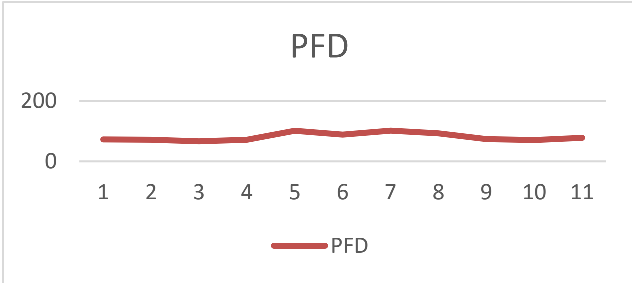


Figure 29: 12 meter long tes tarea for Hortisaber

Comparing present light solution with Hortisaber showing <u>67% saving</u> relative to present HPS light!

	Nuværende HPS	HORTISABER 6m - 1000W			
	400W	330W (33% load)	650W (65% load)	800W (80% load)	1000W (100% load)
Lampe					
Type	HPS (Natrium)	LED			
Fabrikat - model	?	LED iBond			
Dækningsareal - pr lampe [m2]	8,04	20,1			
Antal i test område (6,7 x 12 m)	10	4			
Lysforhold					
Lys energi - LED vs HPS		100%	200%	277%	304%
Lysintensitet (gennemsnitlig) umol/s/m2	40	40	80	111	121
Max intensitet (under lampe) umol/s/m2	52	57	115	149	174
Uniformitet (min/avg.)	65%	82%			
Diversity (max/avg.)	119%	143%			
Spektrum	Standard Natrium	Growth light supplemental			
Energiforbrug					
Effekt pr lampe	400	329	658	800	1000
Effektforbrug pr areal - W/m2	50	16	33	40	50
Effektforbrug – alle lamper - Watt	4000	1317	2634	3200	4000
Besparelse energiforbrug LED vs HPS		67%	34%	20%	0%

Figure 30: Hotisaber is using 67% less energy than existing solution

Figure 31: Hortisaber test area at Hjortbjerg Funen.

7.2.23. Overview of the System architecture of the LED iBond Light/Hort Control Suite

Below is a drawing illustrating the overall system architecture of the LED iBond Light/Horti Software Control Suite.

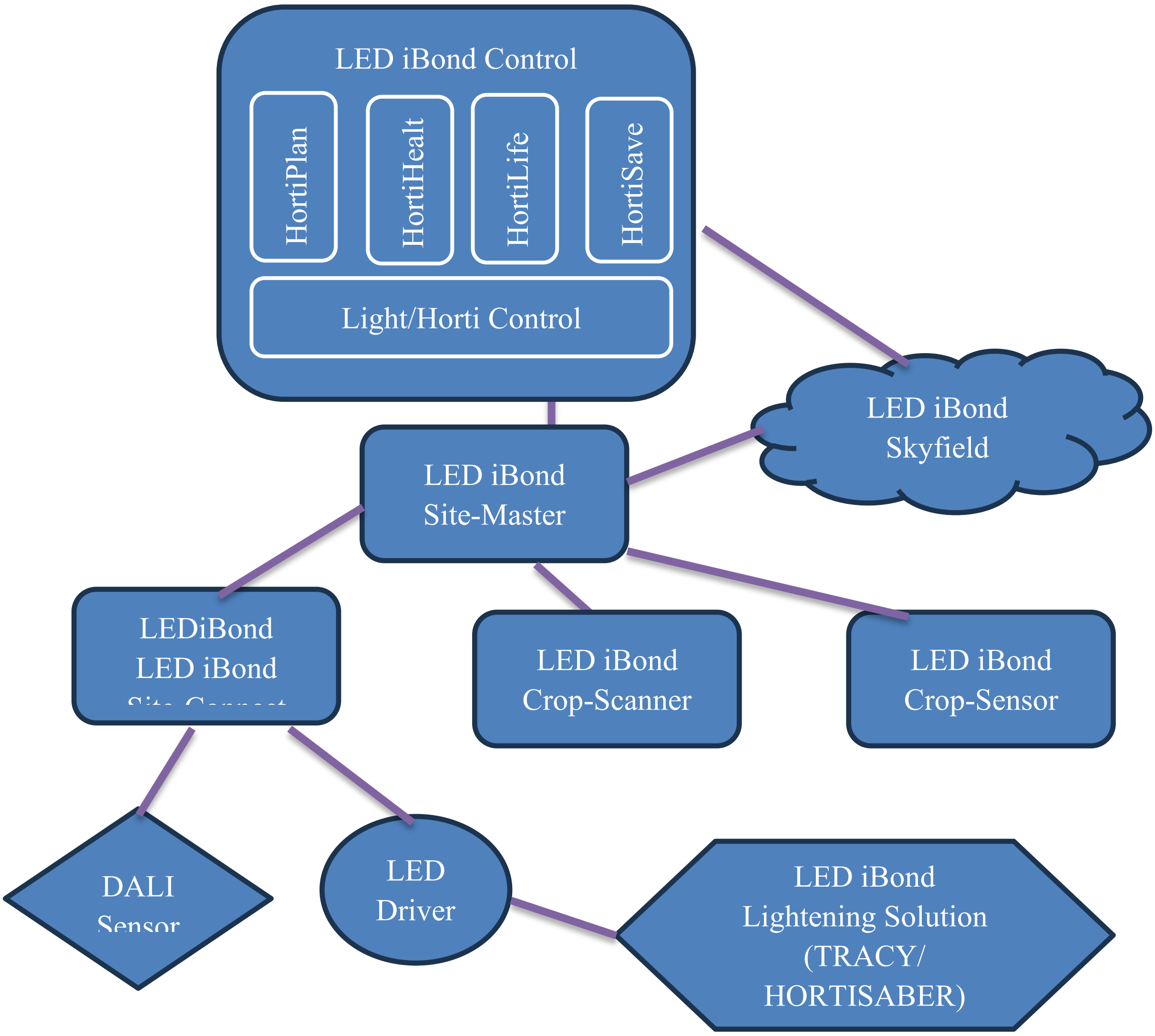


Figure 32: System architecture of the LED iBond Light/Horti Control Suite

Used System Terms

The system above contains several components, which are later explained in this document. To get an overview of these components they are listed below with a short description and a short name which will be used from now on.

The following system terms and short names are:

Term	Short name	Description
Advanced Light Control	ALC	Light control used for garage environment.
HortiControl	HC	Light, grow & climate control used for horticulture environment.
LED iBond Site-Master	MASTER	LED iBond developed intelligent unit for controlling light in many zones and collecting climate data.
LED iBond Site-Connect	CONNECT	LED iBond developed unit connecting e.g., DALI units to the MASTER
DALI PIR sensor	PIR	A movement sensor connected to a DALI bus.
DALI light sensor	LIGHTSENS	A light sensor connected to a DALI bus.
LED iBond Tracy	TRACY	LED iBond developed LED illuminator lamp used for garage environment.
LED iBond Hortisaber	HORTISABER	LED iBond developed LED illuminator lamp used for horticulture environment.
LED driver or Power supply Unit	PSU	A hardware driver delivering a constant current to a LED iBond lightening solution. This driver can be controlled & monitored over a DALI bus.
LED iBond Crop Sensor	CROPSENS	LED iBond developed sensor used to collect data from the local plants measuring moisture, temperature, humidity, air quality (co2), light intensity & position (GPS). This data is send to the LED iBond IoT Cloud solution called Skyfield.
LED iBond Crop Scanner	CROPSCAN	LED iBond developed sensor used to scan over the plants and collect data such as temperature, humidity, air quality (co2), light intensity, position (GPS). But also, a regular HQ camera and IR camera to take pictures of the plants and send to the LED iBond IoT Cloud solution called Skyfield.
LED iBond Skyfield	SKYFIELD	LED iBond developed IoT Cloud system collecting data from an HC. In

		Skyfield an intelligence can interpret the collected data and present used energy, plant health etc. but also predicts the plants health and suggest plant grow conditions.
Light/Horti Control	CONTROL	LED iBond developed graphical control to set up, control and monitor the ALM/HC. This software can either run on the MASTER or in the SKYFIELD. This is the basic required software module for ALC (the called Advanced Light Control) & HC (then called HortiControl).
LED iBond HortiPlan	HORTIPLAN	LED iBond developed a software module to handle production orders and recipes in an HC. This is an add on module to CONTROL.
LED iBond Horti Life	HORTILIFE	LED iBond developed an intelligence software module to proactively change plant grow conditions such as the lighting interval & intensity, temperature, CO2 level, water, fertilizing etc. This is an add on module to CONTROL.
LED iBond Horti Health	HORTIHEALTH	LED iBond developed a software module to monitor the health of the plants by measuring several plant life parameters and present it in graphs. This is an add on module to CONTROL.
LED iBond Horti Save	HORTISAVE	LED iBond developed a software module to calculate and first turn on light when the electricity price is lowest. This is an add on module to CONTROL.

The LED iBond Light/Horti Control is split up into two areas:

- Advanced Light Control (ALC).
- HortiControl (HC).

Both systems are based on the same hardware and software but are fine adjusted for the two different applications. Furthermore, the HC contains components which are not required for the ALC, such as CROPSENS, CROPSCAN, HORTIPLAN, HORTILIF, HORTIHEALTH and HORTISAVE.

Advanced Light Control

ALC is used for garage environment. This system contains a MASTER, and several CONNECT’s, PIR’s, LIGHTSENS’s and a LED iBond lighting solution - TRACY used for garage environment.

This system is explained in section *Advanced Light Control*.

HortiControl

HC is used in the greenhouse environment. This system contains the same units as in the ALC, except for the LED iBond lightening solutions is a HORTISABER. But in addition, the HC can also contain CROPSCAN's and CROPSENS's.

This system is explained in section *HortiControl*.

Advanced Light Control

The ALC is used for garage environment, like the example below.

A parking garage contains only one MASTER, but more CONNECT's – normally only one per floor. The parking garage often contains several floors made of concrete & rebars, which make it difficult to have a good WIFI range between the floors. For that reason, the CONNECT's between the floors can be connected both via WIFI or an Ethernet cable. See the illustration below.

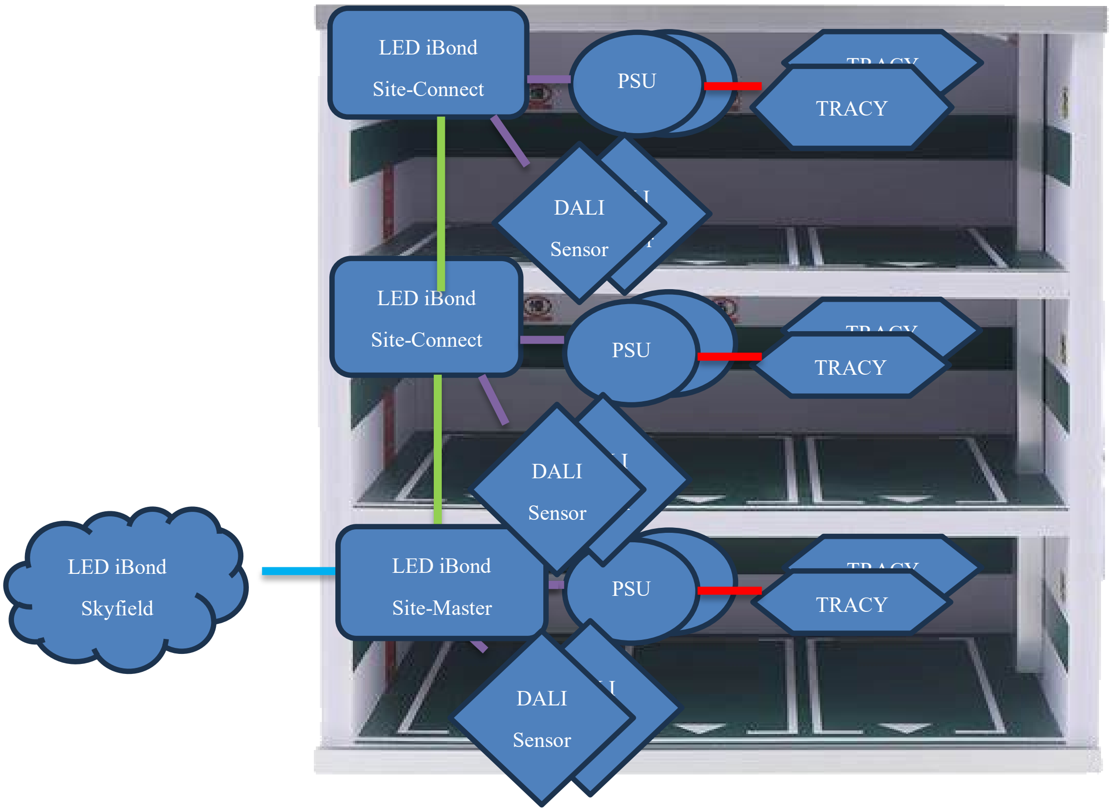


Figure 33: LED iBond system components for multi leveled car park.

The lines in different colors illustrate the different connections:

- Site-Connect connection (Ethernet cable / WIFI)
- DALI cable
- PSU output cable
- Cloud connection (Ethernet cable / WIFI / 4G Lte)

Zones

Each garage floor is normally split up into more zones, but a zone can also be spread out on more floors, like a stairwell. A zone is a collection of *PSU's* which all are controlled with the same light intensity. A Zone has one or more S*cenes*, but only one *Scene* is active at a time. A S*cene* shift can be done using a S*witch* or GUI input.

Below is an example of a garage floor with more zones.

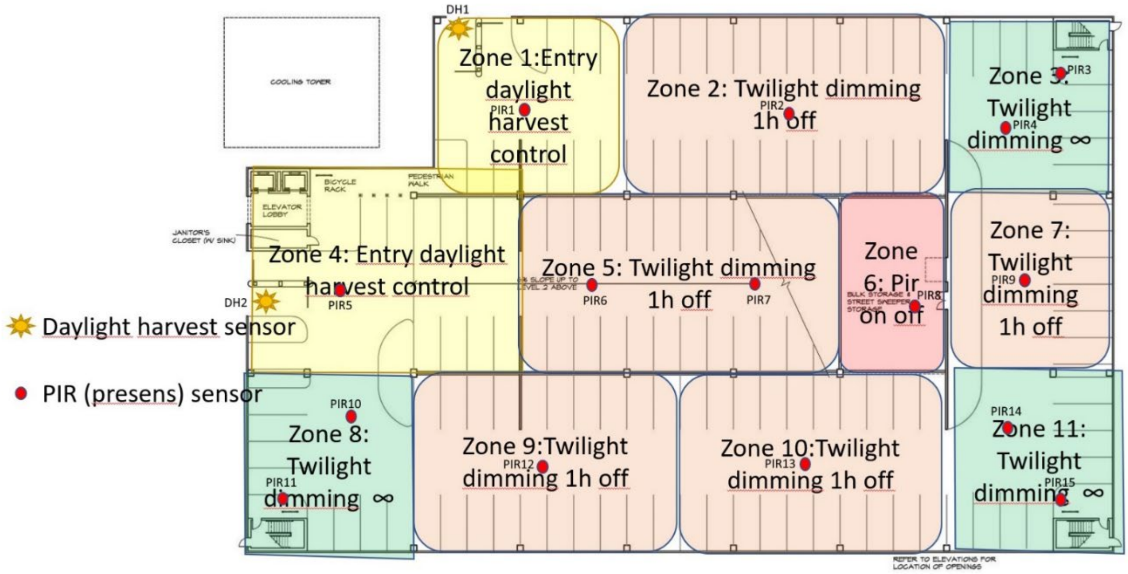


Figure 34: Car Park with four different lighting zones and individual light-programs.

All sensors may be shared between zones, i.e., in the example above the PIR1 sensor in Zone1 is used both to control the light in Zone1, but also Zone2 & Zone5. I.e., when someone enters the Zone1 stairwell, it will turn on the light in the stairwell to 100%, but also turn on the light in Zone 2 & Zone5 to 25%, so the garage floor is not dark when a person enters the garage from the stairwell. First when PIR2 detects the person the light will also turn on to 100% in Zone 2.

Both in zone 1 and zone 4 the “Daylight Harvest” program is used, but in zone 1 the DH1 sensor is used and in zone 4 the DH2 sensor is used.

Another example: in both zone 2 and 5 the “Dimming” program is used, but in zone 2 PIR2 – PIR4 (PIR-A group) will set the LED intensity to 100%, while in zone 5 it is the PIR6 – PIR8 which will set the intensity to 100%.

In zone 2 it is the PIR5- PI15 (PIR-B group) which will set the LED intensity to 25%, while in zone 4 it will be the PIR1-PIR5, PIR9-PIR15.

LED iBond will in the beginning deliver the pre-programmed system consisting of *Zones*, *Scenes* & *Programs*, but the final goal is the end user himself should be able to set up the *Zones, Scenes & Programs*.

The first system has already been sold will be deployed in end of 2023.

ALC Terms

The ALC uses following terms which will be explained later in this document:

Term	Description
Zone	A subsystem which has a collection of *PSU's* which all are controlled with the same light intensity. A Zone has one or more *Scenes*, but only one *Scene* is active at a time. A *Scene* shift can be done using a *Switch* or GUI input.
Switch	A physical switch to make Scene change.
Scene	This is the light controlling state of the *Zone*. Pre-defined Scene by LED iBond are: • Auto • Cleaning • Service The end user can create more *Scenes*. A *Scene* is always running a *Program*. See example of *Scenes* in section **Error! Reference source not found.**.
Program	Making the logic between the input sensors and LED driver output.

Programs

A program is making the logic between the input sensors and PSU output.

A collection of fixed programs is created by LED iBond. Each program will have parameters which are configurable via CONTROL. Examples of programs are:

- *Off()*
- *On()*
- *Set(value) – [value 0-100]*
- *DimTimer(value, time) – [value 0-100], [time 1-n minutes]*
- *Daylight havest(Light Sensor, x1, y1, x2, y2) – [Light Sensor defined in system], [linear scaling from measure µMOL to LED %]*

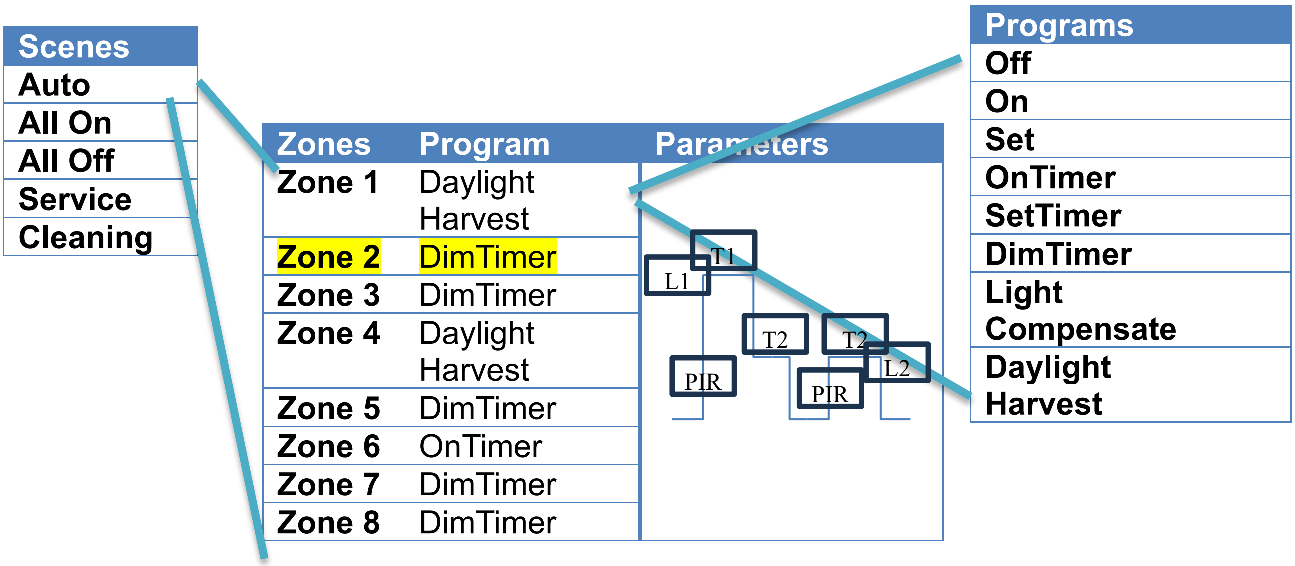
I.e., the end user cannot add a new program, only select a pre-defined one, and which sensors to be used in the program. However, we could make it possible for an end user to clone a program and set the default parameters to something else.

Scenes

Scenes are used to change programs. Normally the "Auto" scene is running which will turn on the light when motion is detected etc. But other scenes are also required when e.g., a service engineer is going to maintain and test the system.

Some pre-defined scenes will be defined by LED iBond, such as:

- Auto
- All on
- All off
- Service
- Cleaning



The graphical interface (CONTROL) will have the "entrance" on scenes. I.e., for each scene the user has to select which program to run in a zone, and with which parameters, like used PIR's, light intensity, timers etc.
The end user can create more *Scenes*. A *Scene* is always running only one *Program*. If a customer needs a new program which cannot be done by the existing, then LED iBond must first develop it.

The predefined programs are explained below:

Name	Description
Off	It does not take any sensor inputs, but only sets all HORTISABER's in the zone to 0 μMOL, i.e., turn them off.
On	It does not take any sensor inputs, but only sets all HORTISABER's in the zone to maximum intensity.
Set	Set the HORTISABER's to generate a specified μMOL. Not the total μMOL may be more, because the sunlight could also make an addition. If the total amount of μMOL wants to be specified, the "Daylight Havest" program should be used.
On Timer	Turn on the HORTISABER's to maximum intensity for T1 seconds, after the T1 expires the HORTISABER's will be turned off.
Set Timer	Does the same as the "On Timer", but the intensity of the HORTISABER's can also be specified.

Dim Timer	No light sensors are used in this program, but several PIR sensor inputs are used. When the program starts all HORTISABER's will be set to 0%. If PIR-A group (a list of one or several PIR's) event is received all HORTISABER's will be set to L1 for T1 minutes, when the T1 timer has expired the HORTISABER's intensity will be set to L2 for T2 minutes, and when the T2 timer expires all HORTISABER's will be set to 0%. If PIR-A group event is received again while the HORTISABER's are on level L1 the T1 timer will be restarted. If PIR-A group event is received again while the HORTISABER's are on L2 level the HORTISABER's intensity will be set to L1 for T2 minutes before falling back to L2 for T2 minutes and then to 0% when T2 timer expires. When all HORTISABER's are off and a PIR-B group event is received all HORTISABER's will be set to L2 for T2 minutes.
Light Compensate	It uses a LIGHTSENS and a specified linear conversion (X1,L1 / X2,L2) from µMOL to all HORTISABER's intensity so if the external light gives X1 µMOL or more the all HORTISABER's intensity is set to L1, and if the external light gives only X2 or less the HORTISABER's intensity will be set to L2.
Daylight Harvest	It only uses a LIGHTSENS and a specified minimum total µmol level, i.e., the summation of both sunlight and HORTISABER light.

GUI for ALC:

The GUI is built up around the Site-plan.

The programming process mirrors the light planning and design process through definitions of light zones, position of PSU and sensors, and safety light.
The selected light programs and status can be monitored and adjusted on a webservice over the a cloud solution.

The effort is laid in an easy-to-use self-explaining user interface for a professional use.

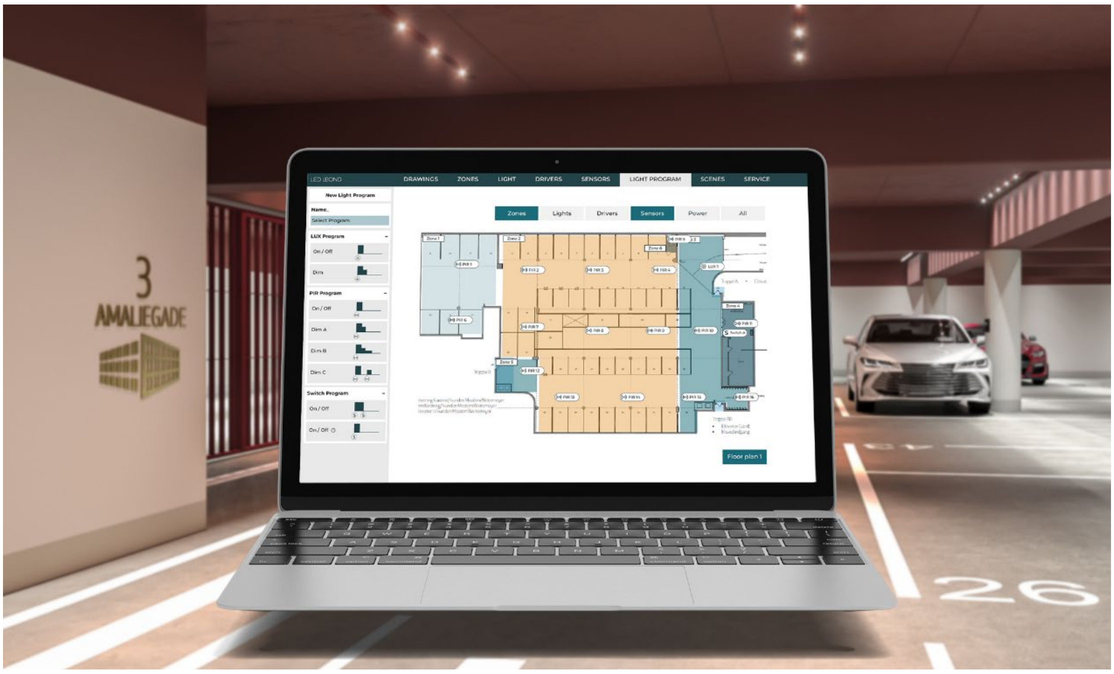
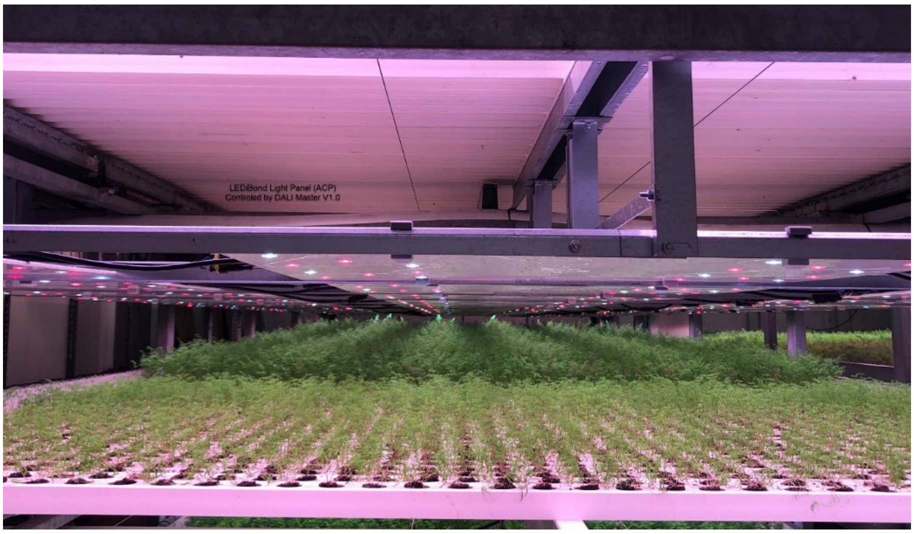


Figure 35: The GUI takes you through the light design phase in recognizable layout pictures

Figure 36: Panels distributed as part of the light programming process.

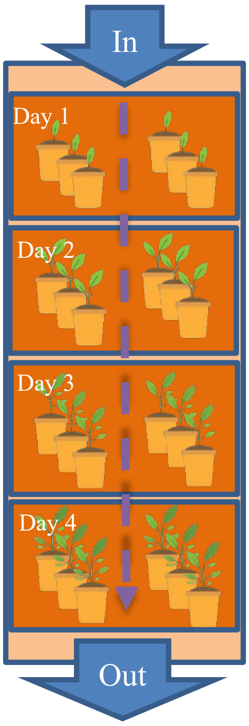
HortiControl

The HC is used for horticulture environment, like the example below.



Horticulture layout

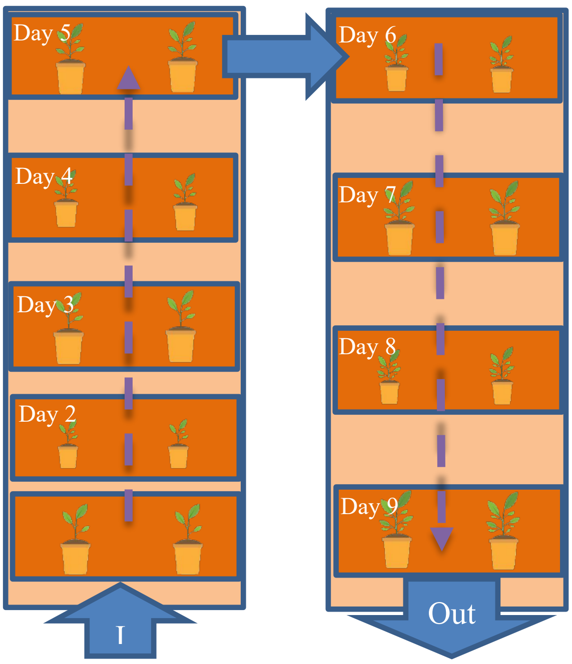
A horticulture plant has several areas, or we will talk about them as zones.



Nursery zone

In the nursery zone daily a tray with several sprouted plants in pots are picked up (from the “Out” zone) and moved to the grow zone. The other trays will automatically move one zone in the “Out” direction. The “In” zone is then filled up with newly sprouted plants.

Grow zone



In the grow zone each of the plants are put in a long tray with only one row. Plants are daily harvested from the “Out” zone, packed and send to the customer. All trays are automatically moving from the “In” to the “Out” zone.
The empty space in the “In” zone is filled up with new trays with plants from the nursery area.
The trays are automatically getting more and more spacing each day.

System

A horticulture system contains only one MASTER, but more CONNECT's – normally only one per room. The connection between the MASTER and the CONNECT's is normally via WIFI, but for longer ranges an Ethernet cable can be used like in an ALC solution.

Unlike the ALC where the light is mainly controlled by PIR sensors, in HC the light is mainly controlled by the kind of plants (a recipe), the amount of received sun light (to compensate for daily absence of required light), and calendar (when to add the artificial light).

A room may be split up into more zones if different light is required in the room. E.g., if a table has a nursery area, and a grow area etc.
The plants may be fixed located but are often moving on a table with a conveyor system. I.e., an order (containing a recipe) must be able to track the plants to give the right light at the given position (zone).

In addition to the ALC the HC can have several additional components like CROPSCAN & CROPSENS to monitor the plants and send the collected data to the SKYFIELD. All this data can be used to optimize the growing process and save energy.

Calendar

Where in ALC PIR sensors are mostly used to control the light, in HC it is more the Calendar, i.e., day clock, weekdays etc. I.e., in an HC system a day clock can be set to when a scene change must happen.
An example of this could be:

- At 01:00 every day (mon-sun) the HC must change to the "Set (300 [µmol])" scene.
- At 06:00 every day (mon-sun) the HC must change to the "Off" scene.

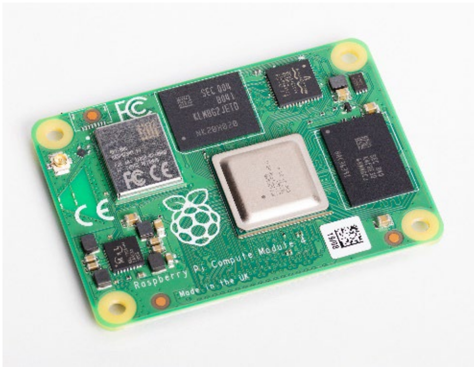
Crop Scanner

The CROPSCAN is a LED iBond developed sensor used to scan over plants and collect data such as temperature, humidity, air quality (CO_2), light intensity, position (GPS) used to correlate the measured values with a position, i.e., an order.

But also, a regular HQ camera and IR camera to take pictures of the plants and send to the LED iBond IoT Cloud solution called Skyfield.

The IR camera I used to measure the leaf temperature, which together with all the other measured parameters will be used to determine the health of the plants. This is the basis together with CROPSENS for implementing HORTILIFE & HORTIHEALTH.

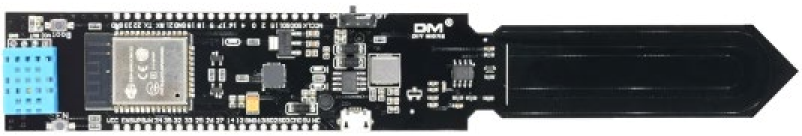
The CROPSCAN will be based on an industrial RaspberryPi CM4 computer (CM4108032 - Raspberry Pi Compute Module 4 - WiFi - 8GB RAM - 32GB Storage • RaspberryPi.dk) connected to a HQ regular and IR camera.
It is powered by PoE (Power over Ethernet) by using an off-the-shelf product like this one.



Crop Sensor

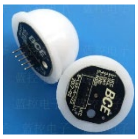
The CROPSENS is a LED iBond developed sensor used to collect data from the local plants measuring moisture, temperature, humidity, air quality (co2), light intensity & position (GPS) used to follow the location of the trays around in the horticulture plant to be able to set the light correctly. This data is sent to the LED iBond IoT Cloud solution called Skyfield.

This is the basis together with CROPSCAN for implementing HORTILIFE & HORTIHEALTH.
It is based on a ESP32 module (ESP32 WiFi SOIL MOISTURE SENSOR).



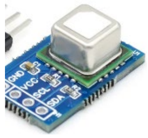
It is powered by a single 18650 LiOn cell

The ESP32 has 5 power modes and can enter very low power consumption (5uA). The goal is to be able to run one month when the LiOn battery is recharged. This means the ESP32 must wake up every 5-10 min do the measurements, send the data via WIFI to the MASTER and enter deep sleep again as fast as possible.



One of the following light sensors will be used:

- BH1750 (Best mechanical form)
- VEML7700 (Best light spectrum)



One of the following air quality sensors (CO_2) will be used:

- ENS160+AHT2x
- SCD40

LED iBond Site-Master

In every system a MASTER is required. It is responsible for communicating with all CONNECT's, execute and save schedules and logics from sensor inputs to PSU's and LED iBond Lightening Solution like TRACY or HORTISABER.

When used in Horticulture environments production orders, recipes etc. are also handled in this device. The MASTER will also host UI which can be accessed from any devices using a WEB browser and who is on the same WIFI network as the Gateway.

That is the installation can run without any Internet connection. The hardware is based on an industrial RaspberryPi CM4 computer (CM4108032 - Raspberry Pi Compute Module 4 - WiFi - 8GB RAM - 32GB Storage • RaspberryPi.dk) running a Linux OS and can be connected to the Internet either by:

- WIFI
- Ethernet cable
- 4G Lte modem with sim card

A Waveshare Industrial RaspberryPi box will be used, which is designed for also having a 4G Lte modem.
It is powered by 24vdc, can be HW configured to support PoE (Power over Ethernet).

The MASTER can also work as a WIFI access point if no dedicated WIFI router is presented (i.e., the system can work without a WIFI access point and

Internet). However, if a WIFI router is present the MASTER will be able to join this as well (i.e., integrate in an existing WIFI network).

If remote access is required, an Internet connection is also required. In this case the MASTER will communicate with a IoT Central Cloud service. When the end user is logged in to this service he can control and monitor all his different installations around the world.
The system may have added sensors of different kinds (light, movement, humidity, temperature, contacts etc.). A lot of these sensors can already be found today, and with different communication interfaces (Modbus, Bluetooth BLE, Zigbee, WIFI etc.). For the wired and wireless sensors with short range (BLE, Zigbee) the sensors will be connected to the “local” CONNECT, which forwards the sensor events to the MASTER. Sensors with long range (WIFI) will be connected to the common WIFI network and communicate with the MASTER MQTT Broker.

Communication architecture

The communication between the MASTER and the CONNECTS, CROPSCAN’s & CROPSENS is using MQTT. The Broker is running on the MASTER.

Control Core

In the RaspberryPi computer a “Control Core” (a service) is running which takes care of all interactions between sensors, calendar and PSU’s and the LED iBond Lightening Solution such as TRACY and HORTISABER.

The interactions (or also known as the programs for the different zones and scenes) a stored in a JSON file, which is created by the CONTROL (a UI program running in a web browser to configure and monitor the system).

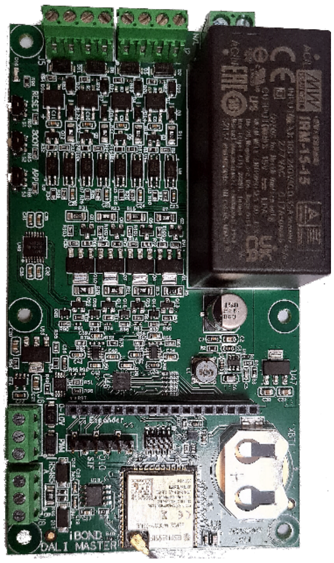
Eventlog database

An database (using SQLite) is created to contain information which later can be used to calculate and present the end user for used and saved energy etc. The database will have a table which has the following fields:

- Time - Unix Time, the number of seconds since 1970-01-01 00:00:00 UTC (INTEGER)
- Zone (TEXT)
- Event – “PIR”, “LS”, ”SetLed” (TEXT)
- Value (TEXT)

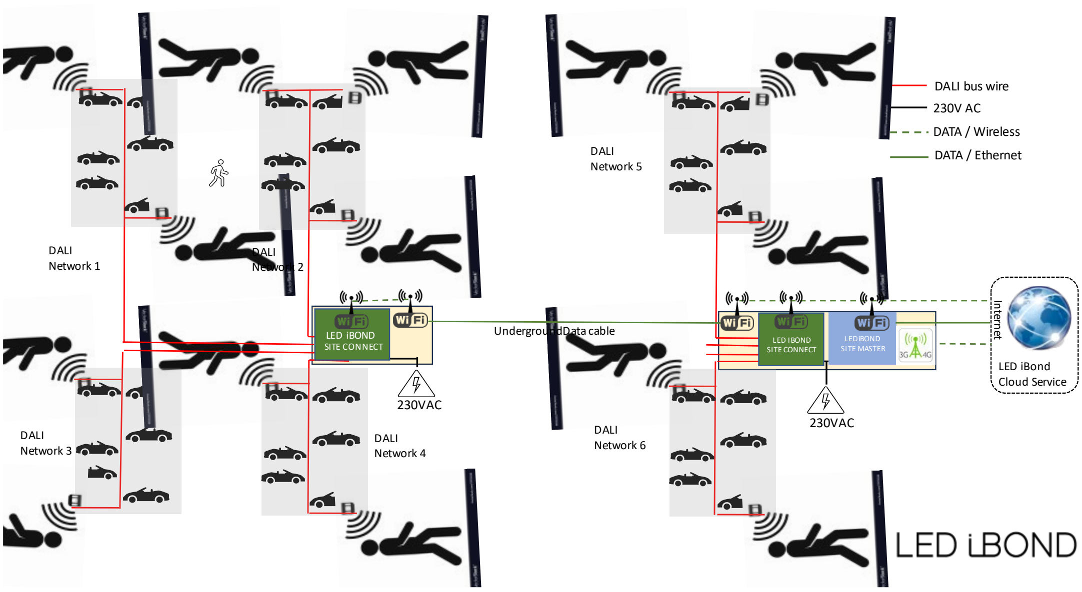
LED iBond Site-Connect

The CONNECT is a LED iBond developed unit connecting e.g., DALI units to the MASTER. It also has other reserved communication channels which can be used in the future. The CONNECT is based on an ESP32 module with embedded Flash, RAM & WIFI. CONNECT is powered with 230vac. The CONNECT specification is:



- 4 x DALI channels. Each can address 64 PSU's and 64 PIR/LIGHTSENS.
- 1 x RS485 half-duplex intended for Modbus supported devices.
- 1 x 0-10v analog output.
- 1 x PWM output.
- 1 x expander connector for future add on.

Here is an example of how a Site connect device is used to connect sensors from across a larger parking area:



Light/Horti Control

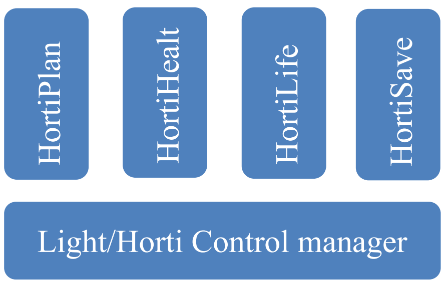
The CONTROL is mandatory software required to configurate, monitor, and run the system. For an ALC application it is called “Advanced Light Control” and for an HC application it is called “HortiControl”.

The CONTROL is divided into following software modules:

- Control Core – Responsible for all interactions between sensors, calendar and PSU’s and the LED iBond Lightening Solution such as TRACY and HORTISABER.
- Control UI – The graphical user interface to configure and monitor the system.

The “Control Core” is running as a service in the MASTER. The input to this program is a JSON file containing information of which programs to run for different zones and scenes, and information about used PIR, LIGHTSENS and Calendar inputs etc.
The JSON file is created by the Control UI software, which is a graphical user interface running in a web browser either in the MASTER or in the SKYFIELD. SKYFIELD is a LED iBond developed IoT Cloud system collecting data from an HC. In Skyfield an intelligence can interpret the collected data and present used energy, plant health etc. but also predicts the plants health and suggest plant grow conditions.

However, more software modules can be added, see the illustration below.



In the project, the core of the control manager and a basic version of the Hortisave has been developed. LED iBond see the value of additional commercial software modules specifically targeted for horticulture industry:

- HortiPlan is a LED iBond (to be developed) software module to handle production orders and recipes in an HC.
- HortiHealth is a LED iBond (to be developed) software module to monitor the health of the plants by measuring several plant life parameters and presenting it in graphs.

- HortiLife is a LED iBond (to be developed) intelligence software module to proactively change plant grow conditions such as the lighting interval & intensity, temperature, CO2 level, water, fertilizing etc.
- HortiSave is a LED iBond (to be further developed as propduct) software module to calculate and first turn on light when the electricity price is lowest.

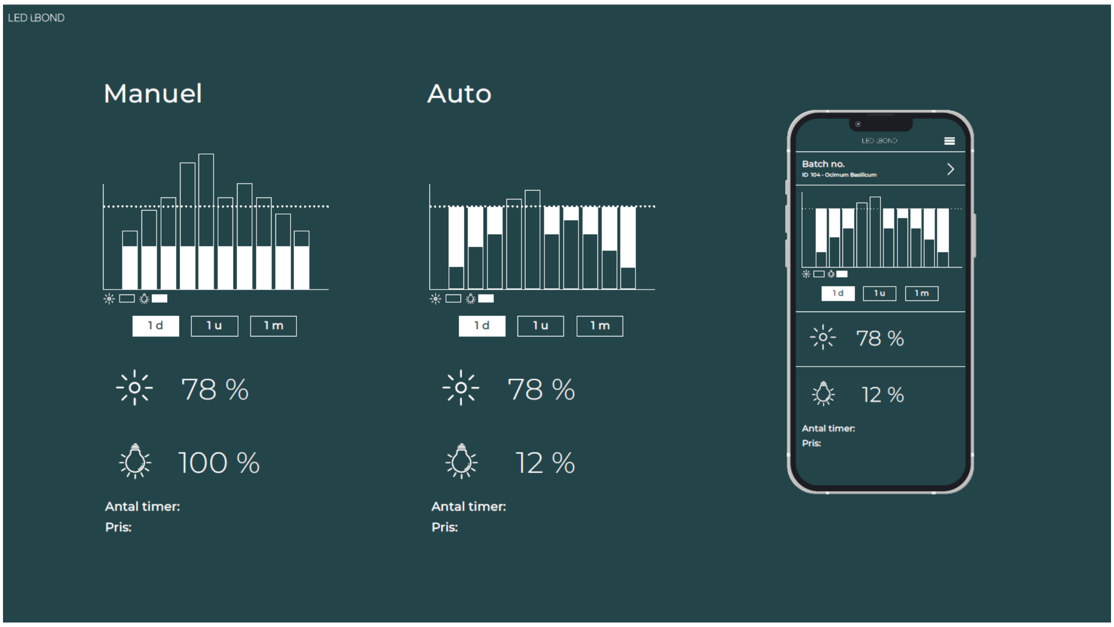


Figure 37: Example of the kind of user interface we are testing in greenhouses

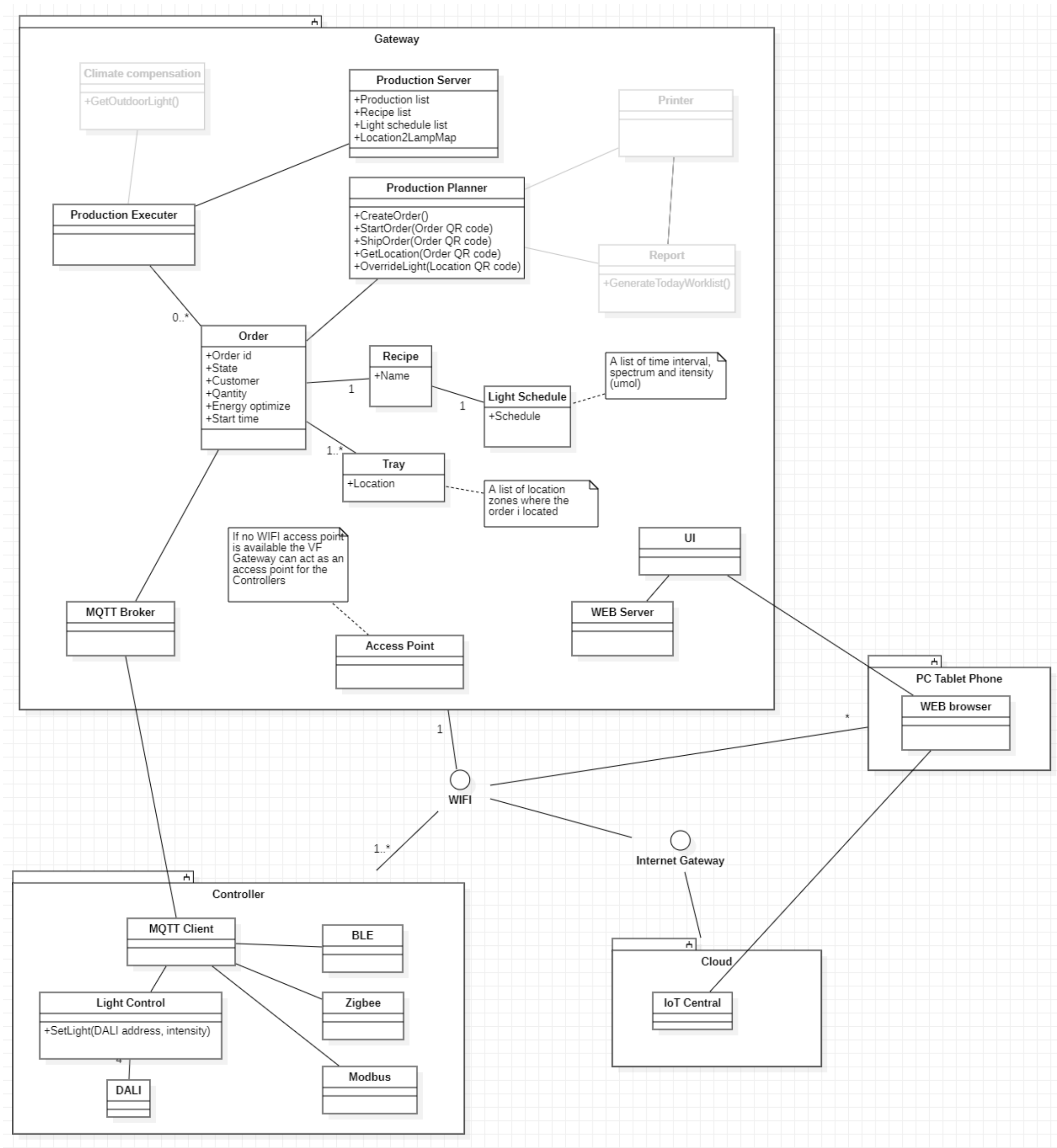
We are deeply aware that software and programs has to be absolutely self-explanatory – and bring immediate value – else it will not be used at all.

7.2.24. Software development framework.

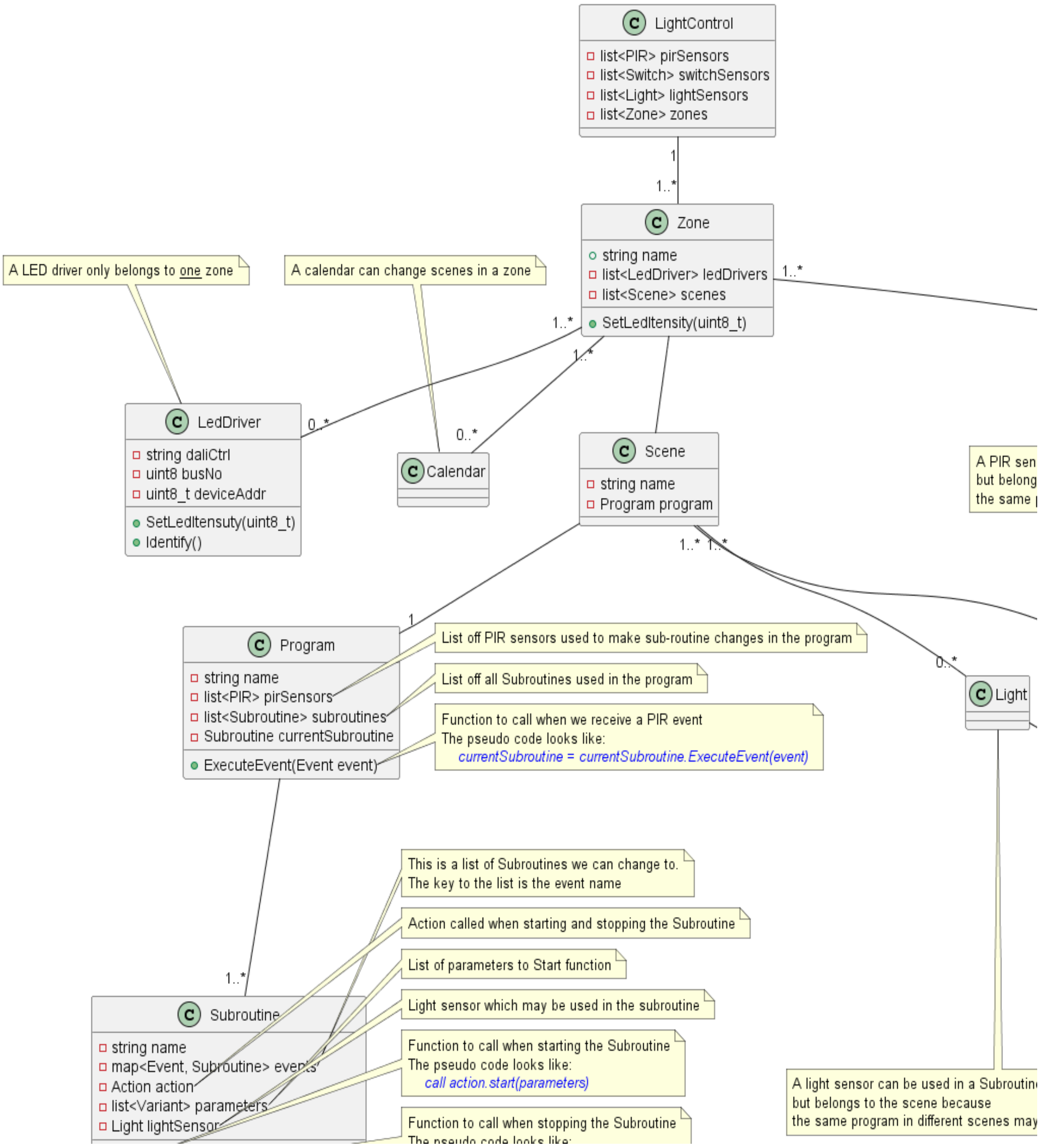
The software is written in C++ 14.

In the Master Gateway it is based on the open Qt framework running on Linux.
For the Connect controller it is based on the Arduino framework running on FreeRTOS.

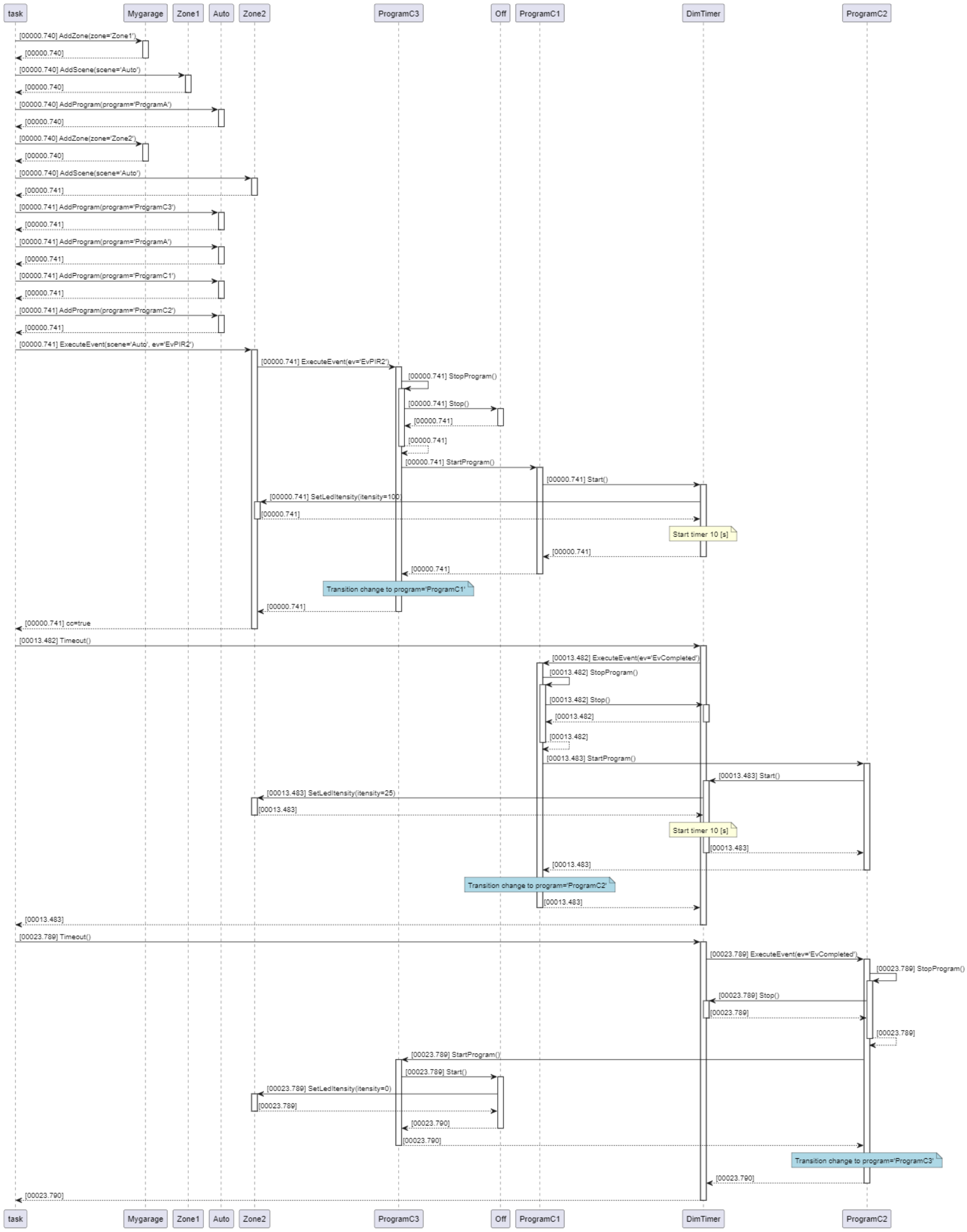
The overall Horti software architecture looks like the UML diagram below.


Gateway
Climate compensation
+GetOutdoorLight()
Production Server
+Production list
+Recipe list
+Light schedule list
+Location2LampMap
Printer
Production Executer
Production Planner
+CreateOrder()
+StartOrder(Order QR code)
+ShipOrder(Order QR code)
+GetLocation(Order QR code)
+OverrideLight(Location QR code)
Report
+GenerateTodayWorklist()
0..*
Order
+Order id
+State
+Customer
+Qantity
+Energy optimize
+Start time
Recipe
+Name
1
1
Light Schedule
+Schedule
A list of time interval, spectrum and itensity (umol)
1..*
Tray
+Location
A list of location zones where the order i located
If no WIFI access point is available the VF Gateway can act as an access point for the Controllers
UI
MQTT Broker
Access Point
WEB Server
PC Tablet Phone
WEB browser
1
*
WIFI
1..*
Internet Gateway
Controller
MQTT Client
BLE
Light Control
+SetLight(DALI address, intensity)
Zigbee
DALI
Modbus
Cloud
IoT Central

The Light Control model looks like the UML diagram below:



Below is an example of what happens when a PIR event is present:



7.2.25. Crop centric control of growth parameters, CropSens and CropScan

From our experience in Vertical farming, we have seen the importance of knowing the growth parameters on crop level rather than on greenhouse level.

The aim is therefore to create a system to collect multiple plant parameter data, to use the data to know what the plant has gone through during the growth process.

Multiple sensor products, already available in the market, were researched and after some scrutinization, the one that fits best for the application was selected.

With the selected sensors a system is designed to collect the data and send them to the cloud to store and analyze later.

Azure Cloud service is being used as the cloud server (Skyfields)

We did not find market available products for data collection that have the functionality we are trying to achieve; therefore it is to a large extend self-developed as described earlier.

There have been 2 prototypes designed and tested.

The first prototype based on standalone sensors in a protected environment (mini indoor farm).

We have seen promising results, with expected correlation between CO2 level around the plant, light intensity, temperature, and humidity. Parameters that in today's green houses are only controlled on "house level" where vertical farming has shown us the value of controlling these parameters based on crop centric measures.

A second prototype is in development and testing, now with components available for building The CROPSENS and CROPSCAN products.

9 essential external parameters + one

At plant level:

1) Ambient Temperature: The air temperature of the growing environment.

2) Relative humidity: The moisture level in the air of the growing environment.

3) Light (Intensity and spectrum): The intensity and spectrum of the light incident on the plant from the light source.

4) CO2: Amount of CO2 present in the growing environment.

5) Wind (Air circulation/Turbulence): The amount of air flowing in the growing environment.

At soil level:

1) Nutrients: Amount of necessary nutrients present in the soil for the growth of the plants.

2) Root zone temperature: The temperature of the soil around the roots.

3) Oxygen levels: Oxygen levels present in the soil around the roots.

4) Water (Moisture): The water or moisture levels present in the soil around the roots.

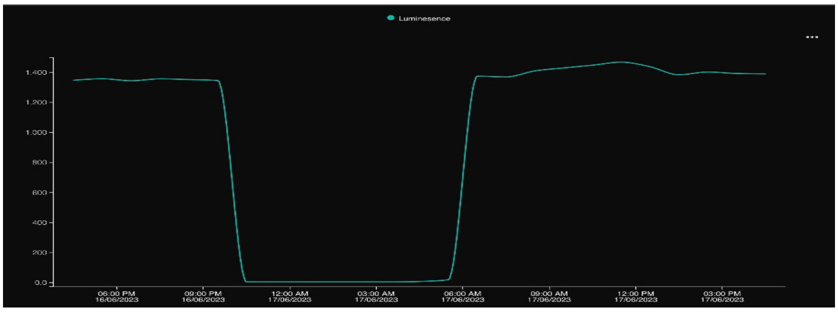
In addition to the above listed "external measurable" parameters, another parameter is the **Leaf temperature,** which gives information on the health of the plant.

7.2.26. Test with collecting real time crop centric growth data.

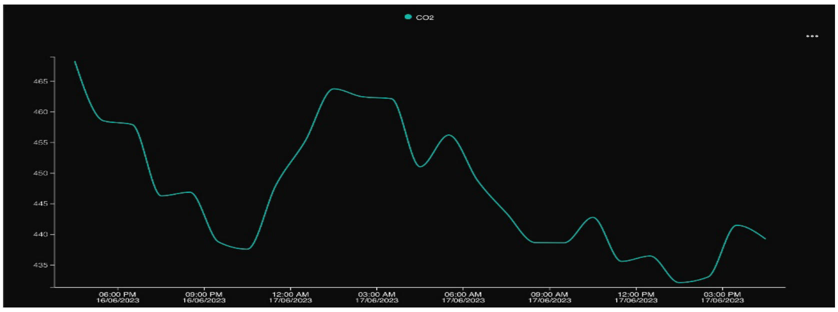
To effectively control light (and other growth parameters) it is no longer enough to have sensors in the greenhouse – you must have it close to the crops and type of crop you grow.

Experiments has been undertaken over this summer and demonstrated that we can measure direct relation between humidity, temperature, CO2 and light level directly at crop level – and combine these data with IR-measurements of leaf temperature as indicator for photosynthesis activity.

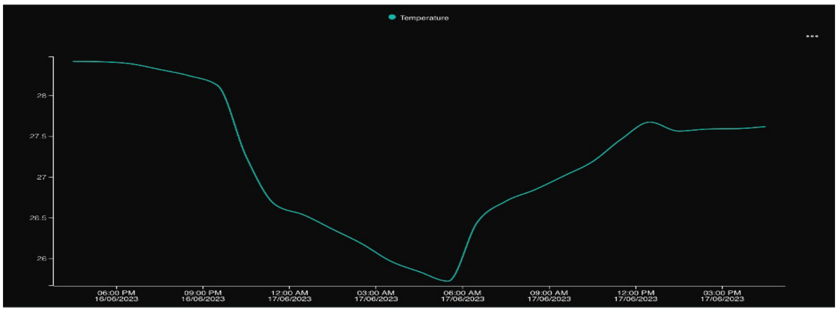
The tests are described in the Master Thesis (hosted by LED iBond in 2023 together with DTU): *Sensor Data Capturing for Yield Optimization*
By Jayashwanth Jeganathan Subhashini



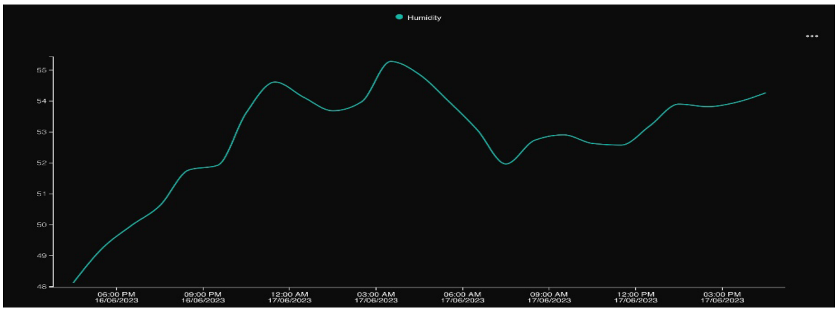
Luminesence: the actual light on the plant – sun or artificial. Here you can see when the light is turned off



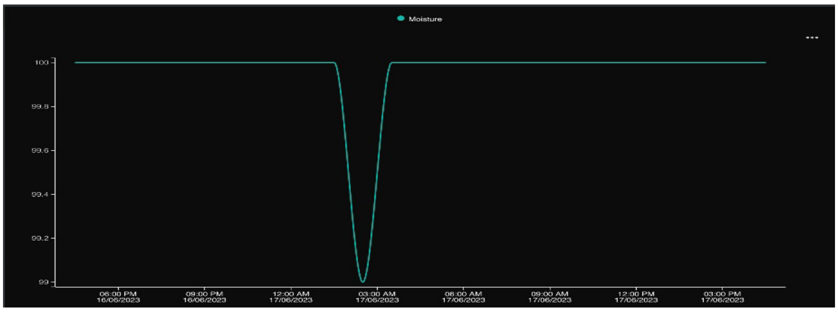
CO2: when the light is on the CO2 level is dropping, and increasing again when the light is turned off



Temp: The temperature is slowly decreasing when the light is turned off.



Humidity: Gradually increases when the temperature drops.



Soil Moisture: Lifting the sensor shows an immediate drop – not long enough to influence the other parameters.

Above you see corresponding values of Light emission, Temperature, CO2 level and Humidity - captured at the growing field.

When moving the test facility into a commercial greenhouse we will get data that can be used for control algorithms at crop level – instead of greenhouse level as today.

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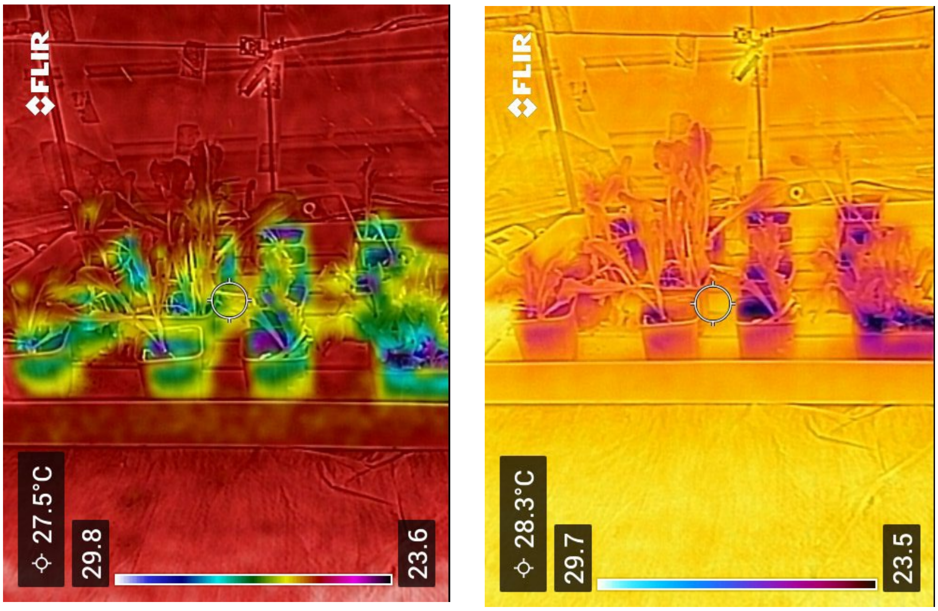


Figure 38: IR pictures of our first test stand - with light and without

We have also made the first test with IR measurement of leaf temperature to see how far we could get with a very simple solution compared to market standard leaf temperature measurement equipment.

The Camera has been refined for the second test where we build everything together in the CROPSCAN module.

1. The project demonstrated in situ data capturing with different sensors
2. API to capture data in LED iBond backend
3. Conveying data to AZURE cloud solution

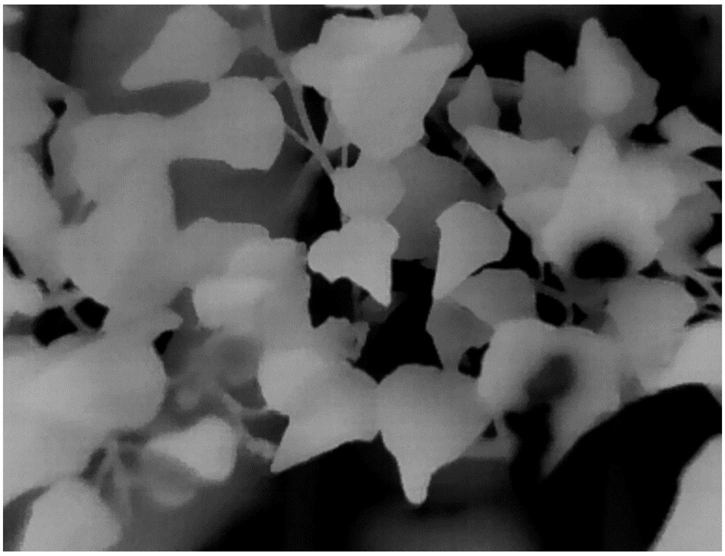


Figure 39: Raw image in White/hot format - Leaf size can be measured – analyzed.

The Xinfrared T3 thermal camera is used to measure the leaf temperature from the CROPSCAN module. The camera captures an image that is in White Hot format where the warmer objects are in white and cooler objects are in black.

The image obtained in raw format itself is in Grey Scale, this palettes offer simplicity for scenes with a wide temperature span and generate images with realistic details. Therefore allowing to find the temperature of the leaves upon processing the image in an Image analysis algorithm. In this way we can derive the leaf temperature of the plants.

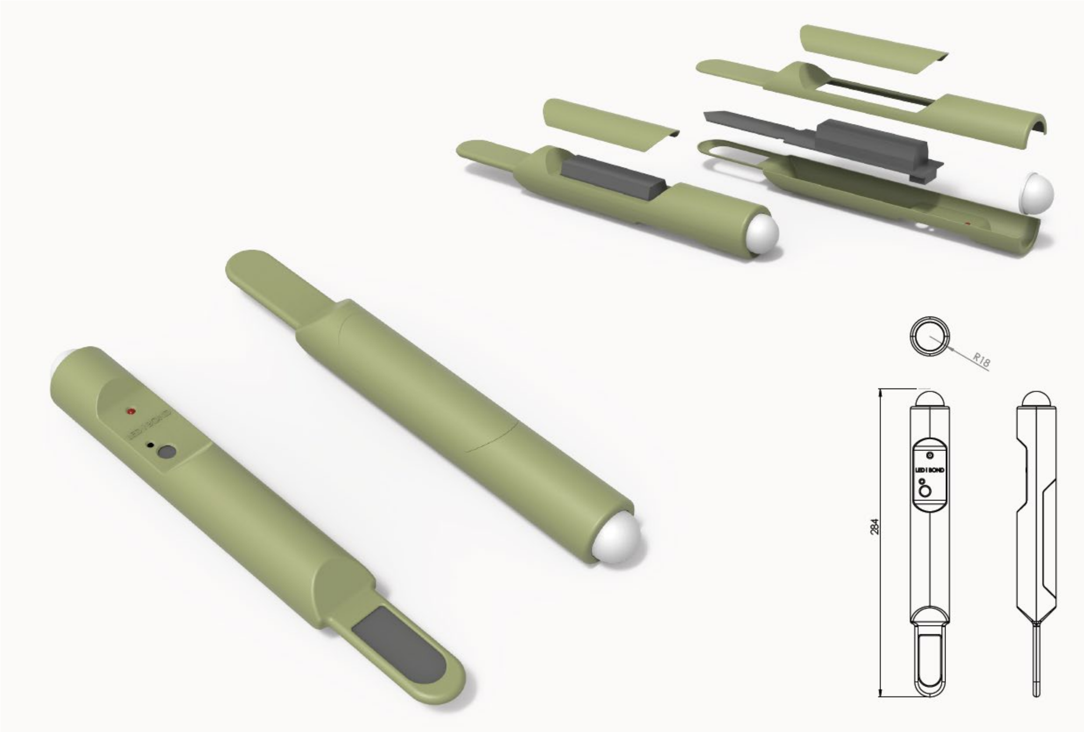
Using this detail we can learn which plants are healthy and which plant might need more attention as they might not be doing well as others.

7.2.27. First model of CROPSENS

We have made a selection of sensors for our first crop sensor

Parameter to be measured	Sensors
CO_2	SCD30
Ambient Temperature	SCD30
Ambient Humidity	SCD30
Light intensity	VEML7700 Ambient light sensor
Soil moisture	Gravity: Analog Capacitive Soil Moisture Sensor
Leaf Temperature	Xinfrared T3

The real test is not the mechanical device – but the meaning, and the use of data we collect. And this again depends on the test we hope to convey in the coming development process with these products, How we present data – and how we can affect controlling of the environment in the green house to be more crop centric.



We only got the parts for the first CROPSENS on November 7th 2023, but expect to have 4 sensors in place at our two test sites within the next weeks.

One set of components are running in our lab in Hørsholm measuring data

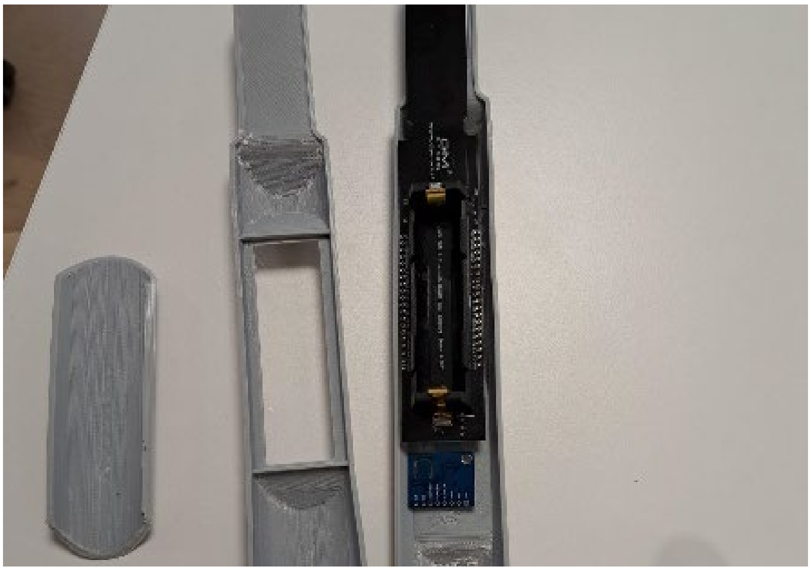


Figure 40: Printed plast parts, together with actual sensor prints

from a mix of cultures.

7.3. *Describe the obtained commercial results. Did the project produce results not expected?*

Parking facilities

The developed solutions for car parking facilities have resulted in great commercial traction and interest. The first commercial break-through for indoor parking garages was a contract won in 2022 (By & Havn Lüders in Copenhagen). The installation was completed in Q4 2022 and have been a great show case for LED iBond and being used in all marketing. See video here: https://LED iBond.com/wp-content/uploads/2023/09/LED-iBond-Parking-Lighting-Solution.mp4

The show case resulted in 3 more contacts in 2023 for 3 other indoor parking garages. One is to be installed in Q4 2023 and will include full scale of the developed light management solution – including all the developed hardware and software (see section 7.2.8 and 7.2.24). This is a key milestone for the LED iBond.

The first show case By & Havn Lüders in Copenhagen have led to interest in particularly from the golf states in the Middel East. Some of the largest parking facilities planned in the world are to be found there.

For solar carports, the developed solutions have led to approximately 10 new customer engagements and sales in Europe and US. LED iBond expects that these engagement over time will develop into larger sales.

Indoor farming

The developed solutions for indoor farming and in particular the HORTISABER have led to enormous interest from the greenhouse industry. The first test installation was completed in Q4 2023, and LED iBond expects the first large scale orders in Q1 2024. The developed software solutions are still in development but LED iBond expects that they will be instrumental for the commercial traction for the sales of HORTISABER.

It is LED iBond believe that the HORTISABER is so unique that it will lead to great commercial traction in 2024.

7.4. *Target group and added value for users: Who should the solutions/technologies be sold to (target group)? Describe each solutions/technology if several.*

7.4.1. Solar carports

Target groups:
Target customer group 1: Manufactures of solar carport solutions
Target customer group 2: General contractors of solar carport solutions

Products:
Product 1: Tracy Industry portfolio (hardware)
Product 2: Light control system (software+Control hardware)

Unique selling points and value:
- Easy and low-cost installation (modular lighting solution)
- Elegant design with slimline form factor
- High energy efficiency

7.4.2. Indoor parking facilities

Target group:
Target customer group 3: Building owners
Target customer group 4: General contractors of indoor parking facilities

Products:
Product 1: Tracy Industry Product portfolio
Product 2: Light control system for Car park areas

Unique selling points and value:
- Easy and low-cost installation (modular lighting solution)
- Elegant design with slimline form factor
- High energy efficiency
- Extra energy saving and better experience with the use of Light control system

7.4.3. Horticulture

Target group:
Target customer group 5: Greenhouse and indoor farm owners
Target customer group 6: Equipment manufacturers for indoor farms

Products:
Product 1: HORTISABER lamp (Hardware)
Product 2: GRACY Horticulture lamp (hardware)

Product 3: TRACY Horticulture lamp (hardware)
Product 4: Horticulture application suite (software + control hardware)

Unique selling points and value:

- Easy and low-cost installation (modular lighting solution)
- High light uniformity
- High energy efficiency (energy saving)
- Extra energy saving and increased production yield (quality) with the use of light control system.

7.5. *Where and how have the project results been disseminated? Specify which conferences, journals, etc. where the project has been disseminated.*

We have had some results to communicate around until recently:

- Some of the results have been published in the master thesis *"Sensor Data Capturing for Yield Optimization"* By Jayashwanth Jeganathan Subhashini, that LED iBond have hosted in 2023 together with DTU.

- We hosted an online Webinar in Q4 2022 about different spectrums and their influence on yield.

- The company Hortiadvice hosted a conference (October 2023) about energy technologies for horticulture, which was the first time we revealed principles about our new Hortisaber product line

- The dissemination will continue after the project end and will be used in marketing efforts in particularly.

8. Utilization of the project results

The project results have led to several products (see section 7.4) being offered to the market. Without the project, these products would not have been developed.

Moving forward, the results of the project will form the base for further product development and a detailed road map for the development of the Horticulture application suite (section 7.2.25 and 7.2.26) – see section 9.3 for further perspective of the results for envisioned software suite.

Without hesitation, LED iBond can say that the project results have been instrumental for LED iBond’s current product portfolio.

9. Project conclusions and perspective

The project has been successful with many valuable results and reached its overall objectives despite that the scope changed during the project. Because of the change, the project has in practice have had two scopes:

Scope 1 (first phase of the project): *LED Light as IoT infrastructure for building and industrial applications*

Scope 2 (last phase of the project): *Tracy and Gracy hardware and software platform for energy optimization in vertical and indoor farming, by intelligent regulation of light and other growth parameters, to optimize the yield from vertical and indoor farms using artificial light.*

Scope 1 and 2 are highly interrelated from a technology point of view and the results and work related to Scope 1, shall be seen as a very important stepping stone for the successful results of Scope 2.

9.1. *Key Technical Results – Scope 1 and 2*

Objective 1: Develop Tracy Software for energy optimization and 3rd party development (Scope 2: Tracy and Gracy hardware and software platform for energy optimization in vertical and indoor farming, by intelligent regulation of light and other growth parameters, to optimize the yield from vertical and indoor farms using artificial light):

Hardware:

- Development of the LED iBond Controller and a LED iBond Master (Back-end) – both have been installed in Horticulture projects and will be deployed in industry projects (parking garages and solar carports) in 2023.

Software:

- Development of software for the LED iBond Controller to operate autonomously as DALI Master and as well as intelligent controller with DALI sensors.
- The software is open for wireless connected sensors of the most “standard” communication protocols”.
- Software for the LED iBond Back-end: handles all sensor data and all operative units (DALI drivers). This is also where the programming of actions takes place depending on data received from various sensors connected to the system.

A suite of algorithms for energy optimization:

- Basic light control solution that can be connected to existing Building management systems (BMS) in buildings or climate computers in Horticulture.
- Sensor operated control from either “daylight harvest” sensors, PIR and Microware motion detection – and/or clock operation.
- Sensors in test in Horticulture: Light sensors, humidity, temperature, CO2, Soil humidity, O2 in soil, Leaf temperature
- IoT: Weather forecasts, Energy prices, Data collection for AI optimization

GUI for LED iBond Light Management Solution:

- GUI that works as design tool (for defining actions & process) as well as control in the same application – with an intuitive interface.

Objective 2: Tracy scalability development to enable higher energy efficiency and faster adoption. (Scope 2: The next generation of led panels with mechanical and electrical upgrades to enable higher energy efficiency, power supply and support of sensors, faster adoption (exchange of existing light), and increased lifetime of the installation)

TRACY product family:

- Cost reduction and upgraded LED technology
- 24VDC for more reach and higher efficiency
- System components for easy adaptation to selected markets
- Simple sensor program for autonomous light control
- IP67 water and dust resistant

GRACY Family:

- Cost reduction upgraded LED technology
- 24VDC technology for single side processing of ACP
- System components for selected markets
- Sensor system for Industry solutions
- IP67 water and dust resistant

HORTISABER:

- Market leading efficiency µmol/J (recognized LED supplier is used)
- Market leading light uniformity – due to patented (pending) optic technology
- “Highly cost effective design” (DFM) – with the use of the absolute optimal manufacturing technologies for the entire lamp
- Ecological-design – the product supports spare part plans – and can be totally disassembled into material fractions.
- Saving 25+% in energy compared to best Natrium lamps in the market.
- Having significantly higher uniformity and efficiency than comparable (competing) LED products

- The product is developed in dialogue with market leading deployment (implementation) company ensuring fast and easy installation design (plug-and-play design with low installation cost).

Objective 3: Develop open source sensor development kit for external IoT device manufacturers. (Scope 2: Create an open data platform for partners to develop algorithms and control systems to further increase yield pr. energy unit.)

- The project did not provide an open source development kit, but instead offer full adoption of industry standard communication protocols in our Hardware and software solutions.
- Sky Fields: LED iBond cloud solution where data from the growth phase and sensors in the grow field is store. The solution also connect external IoT data such as weather forecasts and energy prices to influence control algorithms and action taken.
- Until now only data from LED iBond's own test site (mini farm in lab) have been collected but collections of first real operation data from LEGRO and Hjortebjerg in Q4 2023 is planned.

9.2. *Key Commercial Results – Scope 1 and 2*

The key results from the projects have formed a platform for strong customer dialogue around the world. During the project, TRACY and GRACY Horticulture products have been supplied to many pilot projects around the world (Europe and North America). As a direct outcome of the project's technical results, LED iBond have provided hardware and software to the following Horticulture applications:

- Lettuce (Vertical farms)	(GRACY)
- Strawberries	(GRACY)
- Container for vanilla	(TRACY)
- Cannabis - research (UN funded project)	(TRACY)
- Herb towers	(TRACY)
- Nursery of edible greens	(TRACY)
- Green leaves trolleys (UniTroll)	(GRACY)

As a direct outcome of the project's technical results, LED iBond have also provided hardware and software to the following applications:

- Parking garages	(TRACY)
- Solar Carports	(TRACY)
- Gas stations	(GRACY)

9.3. *Perspective*

The EUDP project has provided LED iBond with very important knowledge both from a technical and market perspective. During the project and based on customer engagement, LED iBond has evaluated the commercial attractiveness of various customer segments and required offering to become successful and competitive.

As an outcome of the project, LED iBond strongly believes that the offering of advanced LED lighting requires sophisticated software management solution to harvest the full potential of the energy saving and value of the LED lighting hardware. Moreover, LED iBond believes that application specific solutions combining highly optimized LED lights with advanced software is essential to be competitive on the global market.

The results from the project clearly indicate that there are attractive opportunities with such solutions within two specific segments:

- Indoor farming for plant and food productions
- Parking facilities (Parking garages and Solar carports)

In particularly, the Indoor farming market is attractive as the value of highly advanced software solutions can have very high value on minimizing energy usages and increase farm production. As an outcome, LED iBond plans to focus on taking the next step by defining a new and ambitious software project: *"Crop centric light management for energy-efficient horticulture production"*.

The objective and key benefits of this new envisioned project is the following:

- **Optimization of iBond HORTISABER LED lighting panel:** this advanced hardware has customizable spectrum options, market-leading efficiency, and uniform light distribution, that will allow to redefine greenhouse lighting. This technology can significantly reduce energy costs as much as 25% (over other LED light solutions), improve crop growth, and replace traditional HPS lamps and 1st generation LED-lamps. During this project the panel will be further developed and improved to work properly in an upscaled greenhouse setting and tested.

- **Development of the LED iBond SkyFields cloud**: this integrated Data Capture and Cloud Solution will act as a centralized hub for capturing, pre-processing, and storing vital environmental and plant-centric data. Through the deployment of sensors, the system captures real-time data related to plant growth, enabling growers to make informed decisions.

- **Development and optimization of LED iBond's suite of software solutions**: **HortiPlan**, **HortiSave**, **HortiLife**, and **HortiHealth**. These software leverages collected data to provide growers with actionable insights. These solutions manage optimal light recipes, energy-efficient lighting strategies, and real-time plant health indicators. This ultimately leads to improved crop yield, energy savings, and efficient resource utilization.

- **Tailored Graphical User Interface and process control**: LED iBond's graphical user interface (GUI) serves as a dynamic tool that intuitively presents historical and real-time data, analysis, and recommendations. This personalized interface ensures growers have a clear overview of their individual production. In this project the GUI will be updated and integrated with

- **LED iBond DALI Master** allows growers to collect data from various sensors and interact with the individual light panels along the life path of his production.

Key Benefits:

- **Optimized Production Process:** By providing light planning that follows the plant through the different areas of the greenhouse, LED iBond makes it possible for growers to streamline their production processes, resulting in higher yields and lower costs.

- **Substantial Energy Savings:** The combined impact of LED iBond light management solution results in significant energy savings across all stages of horticultural production, with potential reductions of up to 62% in energy costs.

- **Enhanced Crop Quality and Yield:** The advanced hardware, data-driven insights, and precise control mechanisms contribute to improved crop quality, accelerated growth, and increased overall yield. First indications (from EUDP 2020 project) show up to 30% additional yield.

- **Cost-Efficiency and Sustainability:** LED iBond's technologies not only save costs through optimized energy consumption but also align with sustainable practices by reducing resource wastage and environmental impact. This ensures that the growers can produce according to specific markets demands and reduce wastage by either increasing or decreasing the growth period through artificial lighting.

- **Future-Proofed Innovation:** LED iBond's ongoing commitment to research and development ensures that growers benefit from continuous advancements in software and hardware, allowing them to stay ahead in a rapidly evolving industry.
  In conclusion, the complete LED iBond light management solution represents an important advancement in horticultural practices. By fully integrating hardware, data capture, cloud solutions, and software, LED iBond empowers growers with the tools and insights needed to achieve remarkable efficiency, productivity, and sustainability in their operations.