Get Ready for Activity – Ambient Day Scheduling with Dementia

Applicable hardware components

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Authors:	Lisa-Marie Neier, Katrin Tanzer, Beat Sauter, Tom Ulmer, Walter Ritter, Sandro Emmenegger
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Project Coordinator:	University of Applied Sciences Vorarlberg (FHV), Austria
Project Partners:	Bartenbach GmbH
	Fachhochschule St. Gallen
	Apollis – Institut für Sozialforschung und Demoskopie O.H.G.
	Intefox GmbH
	Altersheim Stiftung Griesfeld
	EMT – energy management team AG
	CURAVIVA Schweiz
	Tirol Kliniken GmbH – Hall

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Preface

This document forms part of the Research Project "Get Ready for Activity – Ambient Day Scheduling with Dementia (GREAT)" funded by the AAL 2016 "Living well with dementia" funding program as project number AAL-2016-023. The GREAT project will produce the following Deliverables:

D1.1 Medical, psychological and technological framework

D2.1 Applicable hardware components

D2.2 Applicable software components

D2.3 Field tested hardware components

D2.4 Field tested software components

D3.1 Implementation report

D3.2 Field test report

D4.1 Communication strategy

D4.2 Stakeholder management report

D5.1 Report on market analysis

D5.2 Dissemination plan

D5.3 Intermediate business plan

D5.4 Exploitation plan

D5.5 Final business plan

D6.1 Consortium agreement

D6.2 Calendar year report 2018

D6.3 Calendar year report 2019

D6.4 Mid-term review questionnaire

D6.5 Final report

The GREAT project and its objectives are documented at the project website http://uct-web.labs.fhv.at. More information on GREAT and its results can also be obtained from the project consortium:

Prof. Dr. Guido Kempter (project manager), University of Applied Sciences Vorarlberg (FHV), Phone: + 43 5572 792 7300, Email: guido.kempter@fhv.at

Hermann Atz, Institute for Social Research and Opinion Polling OHG (APOLLIS), Phone: +39 0471 970115, Email: hermann.atz@apollis.it

Mag. Wilfried Pohl, Bartenbach GmbH, Phone: +43-512-3338-66, Email: wilfried.pohl@bartenbach.com

Quirino Nardin, Intefox GmbH, Phone: +43 699 1900 8889, Email: info@intefox.com

Dr. Marksteiner Josef, Tirol Kliniken Hall, Phone: +43 (0)50504 33000, Email: josef.marksteiner@tirol-kliniken.at

Mag. Tom Ulmer, University of Applied Sciences St. Gallen (FHS), Phone: +41 71 226 17 41, Email: tom.ulmer@fhsg.ch

Beat Sauter, energy management team ag (emt), Phone: +41 71 660 02 86, Email: beat.sauter@emt.ch

Anna Jörger, CURAVIVA Schweiz, Phone: +43 (0)31 385 33 45, Email: a.joerger@curaviva.ch

Cornelia Ebner, Stiftung Griesfeld, ÖBPB – APSP, Phone: +39 (0) 471 82 63 43, Email: cornelia.ebner@griesfeld.it

Content

1 GREAT Concept

1.1 Overview

The GREAT system should be usable in widely varying environments. Therefore, a highly modular approach has been chosen. Individual components like light, sound, and scent modules can be used individually or in combination. The system also gathers data from motion detectors and physiology sensors worn by caregivers to detect potential activity/relaxation levels of persons in a room. The system can be controlled via a mobile app manually as well as dedicated hardware buttons, that can be added to the system based on local requirements (see Figure 1 for an overview).

One important principle of the GREAT system is that users must always be in full control of the system, meaning that they will always be able to start/stop actions manually.

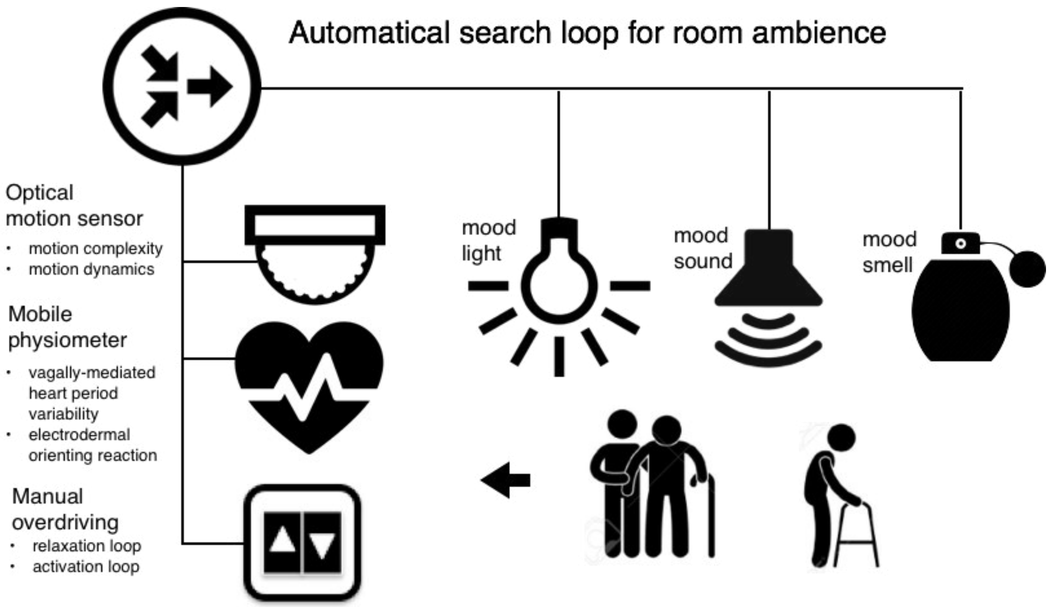


Figure 1: GREAT Components Overview, Source: GREAT consortium

In a first phase, the system gathers data from motion detectors and physiology sensors. Analysis of typical patterns are based on these data. Caregivers are also able to give their current impression of the patient's state (e.g. whether they are very relaxed up to highly activated). During this time, caregivers can manually trigger activation- or relaxation-cycles. For learning purposes, the system logs every activity.
In a second phase, the system recommends to caregivers the triggering of activation-/relaxation-cycles, when it detects certain situations. The actual triggering of these cycles however is still up to the caregivers.

By the end of the field tests, the system should have gathered enough data to trigger activation/relaxation cycles automatically.

2 Light Module

2.1 Basic Considerations

The GREAT lighting system is one of three actuators – light, sound and scent – that want to serve as interventions to help elderly people with dementia to get ready for their daily activities. However, in contrast to the other two actuators, the lighting system also serves another purpose – creating room illumination. Therefore, additional requirements arise for the lighting systems. These and requirements coming from the project goals and the project team are detailed below.

2.1.1 Project's Requirements

- **Biological influence**: The GREAT luminaire should improve the subject's health in the long run, i.e. regulating their activity-rest patterns. For this purpose, the luminaire has to possess tuneable white and biodynamically control of the lighting over 24 hours.
- **Acute Interventions**: Furthermore, the luminaire must be able to influence the elderly people with dementia immediately through acute interventions such as activation or relaxation.

2.1.2 Visual Requirements

In general, there are recommendations from earlier projects at Bartenbach for higher visual requirements in elderly that should be considered in lighting concepts:

- **Light intensity** at task area: $0.3 < E_{cylindric}/E_{horizontal} < 0.6$ at eye level and at height of desk
- **Maximal luminance** in range of vision: 1000 cd/m² (avoids glare in elderly with higher sensitivity to glare)
- **Horizontal luminance** in task areas for elderly should provide 1000 Lux during the day and 300 Lux during the night
- **Spectral quality** should provide a colour rendering index of at least 80
- **Avoid multiple shadows**
- **PWM-dimming frequency** >1,25 kHz

2.1.3 Requirements from Application

- **Room Size**: Minimum requirement is to lit a space of 9 m² homogenously. The goal is to reach 16 m² to be able to illuminate most rooms completely without additional lighting.
- **Target group** are elderly people with dementia.
- **Usage**: The luminaire should be suitable for use in retirement and nursing homes as well as in hospitals. Here, the predominant areas of usage are common rooms and bedrooms of the patients as well as the common rooms of the nursing staff. Furthermore, the luminaire should be used in private settings, i.e. in bed or living rooms in the rooms of elderly people with dementia.

These divergent operational scenarios propose a substantial challenge for the development of the luminaire as for example illuminating a living room scenario is very different from a dining area in a nursing home.

- **Setup**: The luminaire should be easily accessible and not entail high installation costs. Furthermore, mobility of the luminaire is encouraged.
- **Operation**: The luminaire should be easily operatable by the nursing staff and partly, by the elderly people with dementia.

2.1.4 Technical Requirements

- **Flexibility**: The luminaire should possess flexibility in operation to a certain extent. Room lighting and task lighting have to be controlled separately.
- **Safety**: Since the luminaire will be used in care applications and hospital surroundings there are high safety-related requirements. Behaviour based on rationality or reflexive behaviour cannot be taken for granted. Special protection is required against
  - electric shocks
  - glare
  - hot parts
  - tilting of the luminaire

2.1.5 Requirements for Environment

- White ceilings and walls: Best effectiveness is expected if walls and ceiling are white painted because reflectance of light is optimal under these conditions.
- Missing daylight: Artificial light interventions reach best effectiveness if there is small or no daylight entry to the lighted room.

2.2 Lighting concept and control algorithm

The lighting concept contains a fixed biodynamic lighting curve, regulating activity-rest-patterns on the long term, and dynamically applicable light interventions leading to acute activation or relaxation. The biodynamic lighting curve integrates a light dose approach (vertical illuminances ~ 500 lux), dawn-dusk simulation (variations in light levels and additionally coupled with variations in colour temperature) and a variation of the lighting environment during the siesta. Special visual requirements of elderly people will be considered at any time of the biodynamic curve. Beside the two light interventions, activation and relaxation, a TV scene will be provided to create a cosy and relaxing lighting ambience while watching TV. The lighting system will be controlled via User-Interface/App and a switcher for dimming.

Indirect- (ambient room lighting) und direct-components (task light for spaces with special visual requirements) will be controlled dynamically in dependency of daytime.

The ambient room lighting is superficial to reach vertical illuminances at the eye of an observer to provoke positive effects on his health. The task light is necessary to provide load-free vision and to add on vertical illuminance levels. Vertical illuminances must be reached at any observer position in the specified room, quantified at a reference point. Figure 2 shows a scheme of the biodynamic lighting curve in a 24-hours cycle.

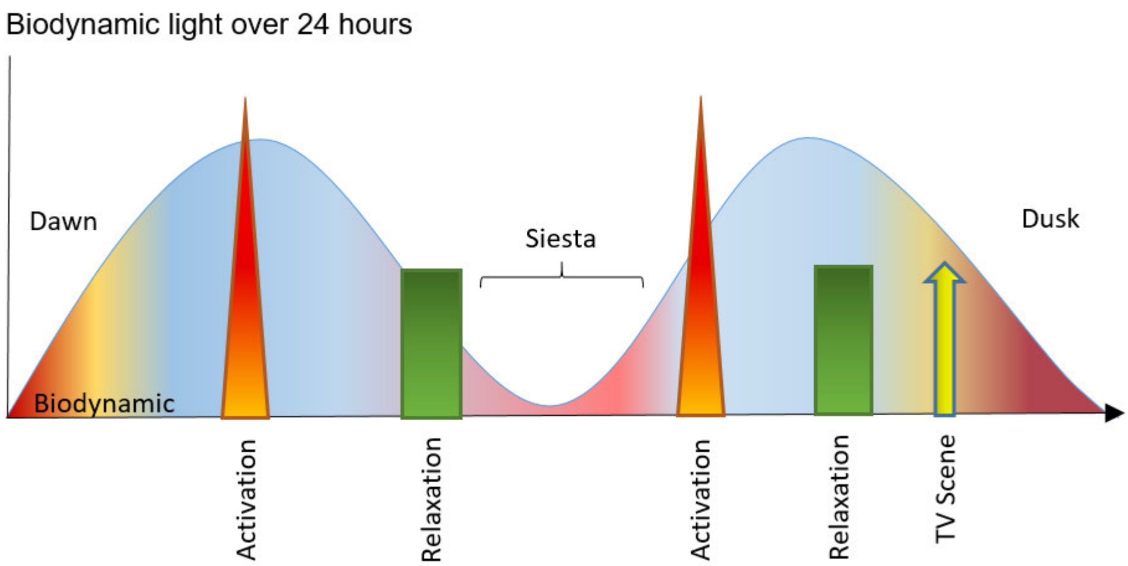


Figure 2: Schematic representation of the lighting solution in GREAT. Biodynamic light will be a fixed curve, light interventions (activation, relaxation, TV scene) will be adjustable in a timely flexible manner (during a specific time span).

2.2.1 Light concept in detail

Biodynamic lighting concept:

These lighting concept should provide a stabilization of sleep-wake-cycles in the long run and lead to stabilized activity-rest-patterns with high activity peaks in the early morning and early afternoon und low activity levels in the siesta and in the evening before going to bed. High illuminance levels and spectral distribution peaking in blue light in the early morning should activate the observer. Reduced illuminances and lower colour temperatures in the siesta time and evening should ease relaxation and prepare an observer for going to sleep. Due to this rhythmical change in light intensity and colour temperature as well as focusing on reaching a high light dose during the day, we expect positive effects on general health of elderly people with dementia.

A special task light will provide lighting conditions for optimal visual information processing, especially for older people with demanded visual requirements. We expect positive effects of this special task light on general health as well (e.g. more active commitment in social networking: playing cards, reading, handicrafts, etc.).

Dynamically controlled light in dependency of daytime:

Morning (ca. 7.00 a.m. (depends on wake-up time – adjustable at the user-interface) – 12:00):

The biodynamic starts at 7.00 a.m. in the morning automatically and wakes a person up with increasing horizontal illuminances (task + indirect light) from 0 to 1000 lux (=100%) and vertical illuminances from 0 to 500 lux over 30 minutes (Note: it is important to avoid glare through task lighting for persons laying in the bed). Simultaneously, colour temperature rise from 2200 Kelvin up to 4000 Kelvin linearly. Light settings maintain the same until siesta (ca. 12.30 p.m., adjustable)

- Dawn simulation
    - Direct lighting - downlight (task light):
        - Within 30 min linearly from 0 lux to 1000 lux (100%) horizontal illuminances
        - Simultaneously colour temperature (CCT) increases from 2200 K to 4000 K linearly
    - Indirect lighting - uplight (ambient room lighting):
        - Within 30 min from 0 lux to 500 lux (100%) vertical illuminance at the eye level (1.6 m); this increase is accompanied by an increase in horizontal illuminance from 0 lux to 1000 lux (100%) in this area
        - Simultaneously CCT increases from 2200 K to 4000 K

Siesta (after lunch, time adjustable via user-interface, duration of siesta lighting scene: 1 hour, assumed time ca. 12.30-1.30 p.m.):

After lunch lighting varies to provide a relaxing ambient during the siesta (currently: closed curtains and lights-off in facilities). Therefore, horizontal illuminance of the task light will be reduced from 1000 lux to 120 lux, horizontal illuminance from ambient light will be reduced from 1000 lux to 50 lux, which is accompanied by a reduction in vertical illuminance from 500 to 20-30 lux. Simultaneously, colour temperature will be linearly reduced from 4000 K to 2700 K over 30 minutes. The aim of this variation in lighting condition during the siesta is to avoid manually switch-off of the biodynamic lighting, which often leads to lights-off periods for the rest of the day.

- "Cosy" dynamic
    - Direct lighting – downlight (task light):
        - Reduction from 1000 lux to 120 lux (12%) in 30 min linearly
        - Simultaneously CCT reduced from 4000 K to 2700 K
    - Indirect lighting – uplight (ambient room lighting):
        - Reduction in horizontal illuminance from 1000 lux to 50 lux (5%) over 30 min; this is accompanied by a reduction in vertical illuminance from 500 to 20-30 Lux (~25%)
        - Simultaneously CCT reduced from 4000 K to 2700 K

Afternoon (after 1.30 p.m.):

Variations in lighting conditions should activate persons with dementia for different tasks (social networking, visits, etc.). Welcomed side-effect is that these persons will be more tired in the evening to enhance good sleep.

Therefore, illuminances will be increased linearly over 15 minutes. Horizontal illuminance from task light will increase from 120 lux to 1000 lux, horizontal light from ambient room light will reach 1000 lux from 50 lux and vertical illuminance thereby increases from 20-30 lux to 500 lux. Colour temperature simultaneously increases from 2700 K to 4000 K. Lighting conditions then maintain the same until dusk simulation.

- "activating" dynamic in the afternoon
    - Direct lighting – downlight (task light):
        - Horizontal illuminances increase linearly over 15 min from 120 lux to 1000 lux (100%)
        - Simultaneously CCT increases from 2700 K to 4000 K
    - Indirect lighting – uplight (ambient room lighting):
        - Vertical illuminances increase linearly over 15 min from 20-30 lux to 500 lux (100%) and horizontal illuminance increases from 50 lux to 1000 lux (100%)
        - Simultaneously CCT increases from 2700 K to 4000 K

Evening (time adjustable via user-interface, assumed time ca. 8 p.m.):

In the evening dusk-simulation should ease transition from active to resting phase by relaxing persons with dementia. Therefore, a linear reduction in illuminances of the task light from 1000 to 300 lux, illuminances of ambient room light from 1000 to 50 lux, accompanied by a reduction in vertical illuminance from 500 to 20-30 Lux will be performed. Simultaneously, colour temperature will be reduced from 4000 to 2700 K.

Reduced colour temperature furthermore avoids melatonin suppression. These light settings will maintain the same until 9.30 p.m. and then change to night mode.

- "Dusk-simulation"
  - Direct lighting – downlight (task light):
    - Reduction in horizontal illuminance from 1000 lux auf 300 lux (30%) over 30 min
    - Simultaneously CCT is reduced from 4000 K to 2700 K linearly
  - Indirect lighting – uplight (ambient room lighting):
    - Horizontal illuminance reduces from 1000 to 50 lux (5%) linearly over 30 min; this is accompanied by a reduction in vertical illuminance from 500 to 20-30 lux (~25%)
    - Simultaneously CCT is reduced from 4000 K to 2700 K linearly

Note:

Starting point of the dusk-simulation should vary with season, that means that earlier dusk-simulation in winter and later dusk-simulation in summer should be provided (time adjustable via user-interface)

Night (9.30 p.m. -7 a.m.):

It is assumed that light will be switched off during the night (by caring-stuff or caring-person). But if there is light necessary during the night, area should be lighted with 300 lux horizontal illuminance from task light and 25 lux vertical illuminance. Colour temperature will chance linearly at 9,30 p.m. from 2700 K to 2200 K over 15 min providing melatonin light.

Biodynamic lighting system automatically starts again at 7 a.m. with dawn-simulation. If lighting system is already switched on, dawn-simulation starts rising from the current level (Eh = 300 lux, CCT = 2200 K or if dimming was performed, rising begins from that levels).

- Night light
  - Direct lighting – downlight (task light):
    - Horizontal illuminance 300 lux (30%)
    - CCT linearly falls from 2700 K to 2200 K within 15 min
  - Indirect lighting – uplight (ambient room lighting):
    - Horizontal illuminance < 50 Lux (5%), accompanied by a vertical illuminance from 25 Lux (20%)
    - CCT linearly falls from 2700 K to 2200 K within 15 min

The biodynamic lighting concept is visualized in Figure 3. The table illustration (Table 1) shows illuminance levels and colour temperature values at given times over 24 hours in detail for horizontal and vertical illuminances.

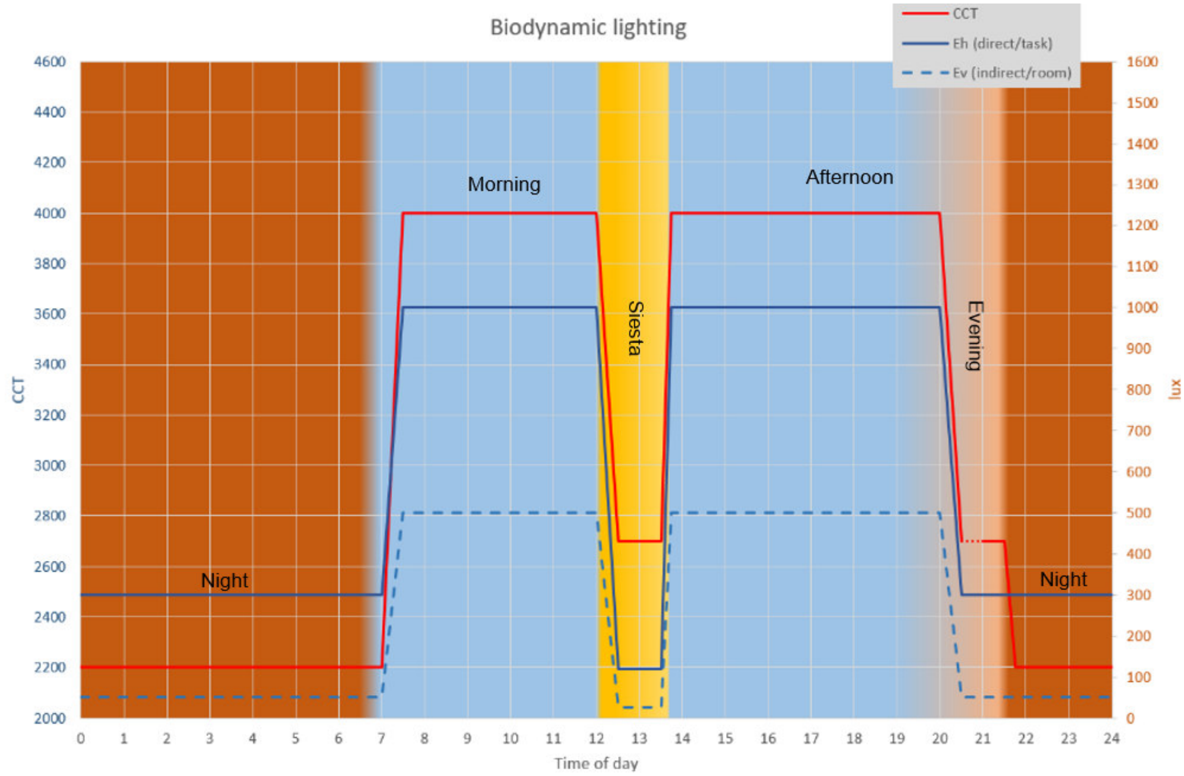


Figure 3: Biodynamic lighting concept. CCT…colour temperature in Kelvin, Eh…horizontal illuminances of the task light, Eh_{Room}…horizontal illuminance of ambient room light (resulting from Ev + Eh Task, for clarity reasons Eh_{Room} is not shown), Ev…vertical illuminance at the eye level

Table 1 : Table illustration of illuminances and colour temperature, varying within 24 hours. In blue: changes in illuminances and/or colour temperature. In pink: constant lighting conditions. Eh_{STask}…Start Eh of task light – downlight, Eh_{ETask}…End Eh of task light – down light, Eh_{SRoom}…Start Eh at reference point, Eh_{ERoom}…End Eh at reference point, Ev_{SRef}…Start Ev at reference point, Ev_{ERef}…End Ev at reference point, CCT_S…Start CCT in Kelvin, CCT_E…End CCT in Kelvin

Start time	End time	Eh_{STask} [lux]	Eh_{ETask} [lux]	Eh_{ETask} [%]	Eh_{SRoom} [lux]	Eh_{ERoom} [lux]	Eh_{ERoom} [%]	Ev_{SRef} [lux]	Ev_{ERef} [lux]	CCT_S [K]	CCT_E [K]
7.00	**7.30**	50	1000	100	50	1000	100	0	500	2700	4000
7.30	**12.00**	1000		100	1000		100	500		4000	
12.00	**12.30**	1000	120	12	1000	50	5	500	25	4000	2700
12.30	**13.30**	120		12	50		5	25		2700	
13.30	**13.45**	120	1000	100	50	1000	100	25	500	2700	4000
13.45	**20.00**	1000		100	1000		100	500		4000	

20.00	**20.30**	1000	300	30	1000	50	100	500	25	4000	2700
20.30	**21.30**	300		30	50		5	25		2700	
21.30	**21.45**	300	300	30	50	50	5	25	25	2700	2200
21.45	**07.00**	300		30	50		5	25		2200	

Additional light interventions and light scenes

There are three light interventions that can overwrite the biodynamic curve: light cues that activate or relax an observer acutely:

- Activating light cue: sudden increase in illuminance after a short reduction
- Relaxing light cue: reduction in illuminance and colour temperature
- TV scene: specific ambient lighting to provide a cosy ambience during watching TV

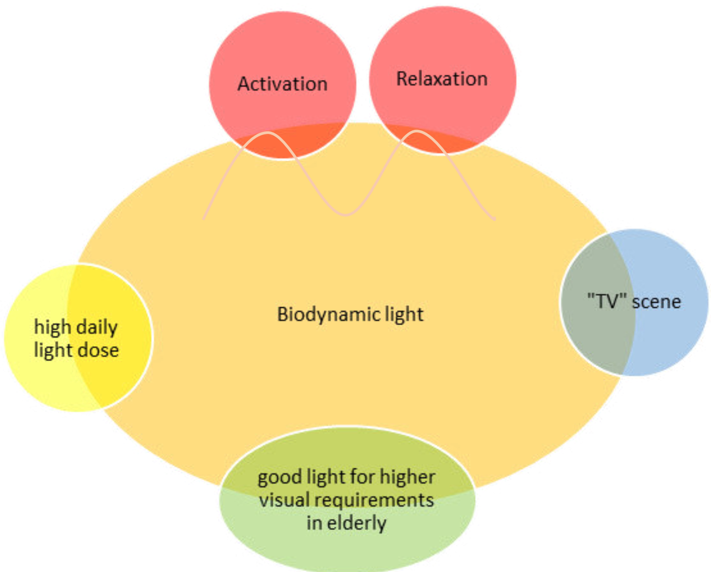


Figure 4: Lighting concept

Activation via light cue

An activating light cue starts with an unrecognisable reduction in vertical illuminance of 50% relative to original value. This reduction needs 5 min. After that a recognisable increase in vertical illuminance up to 600 lux (120%) will appear. Directly after reaching the peak a slow linear reduction back to the original value will be performed over 15 min. Activating cues can be used between 8 a.m. and 7 p.m. The usage is limited for reasons of wrong usage to late at the day (e.g. activating shortly before going to bed).

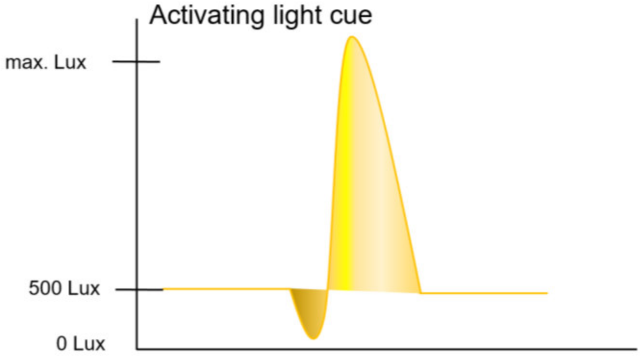


Figure 5: Activating light cue

- Direct lighting – down light (task light):
    - Reduction of the horizontal illuminance to 50% over 5 min, followed by a sudden increase to the maximal level of lux (short overdrive) that can be reached over 5 seconds, followed by a slow reduction (15:55 min) back to original illuminance levels.
    - CCT = 4000 K
- Indirect lighting – uplight (ambient room lighting):
    - Reduction of the horizontal illuminance to 50% over 5 min, followed by a sudden increase to the maximal level of lux (short overdrive) that can be reached over 1 min, followed by a slow reduction (15 min) back to original illuminance levels.
    - CCT = 4000 K

Relaxing light cue

For relaxation, a reduction in illuminances and colour temperature will be performed. In detail, horizontal illuminance will be reduced to 120 lux, vertical illuminance to 20-30 lux (~25%) and colour temperature to 2700 K within 10 min. These light settings stay constant for 40 min. Afterwards light settings will increase back to origin light levels.

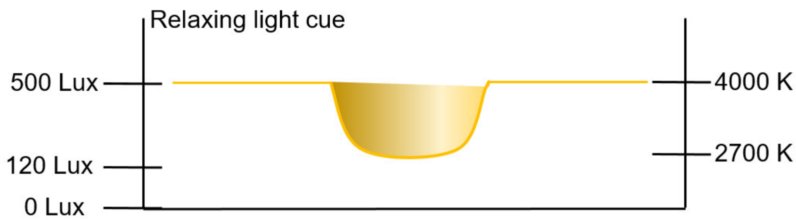


Figure 6: Relaxing light cue

- Direct lighting – down light (task light):

  - Start: within 10 min from Eh_{Task} = 1000 to 120 lux [1] (12%), CCT from 4000 K to 2700 K
  - End: within 10 min from Eh_{Task} = 120 to 1000 lux (100%), CCT from 2700 K to 4000 K
- Indirect lighting – uplight (ambient room lighting):
  - Start: within 10 min Eh_{Room} from 1000 lux to 50 lux (5%), accompanied by Ev from 500 lux to 20 - 30 lux (~25%) und CCT from 4000 K to 2700 K
  - End: within 10 min Eh_{Room} from 50 lux to 1000 lux (100%), accompanied by Ev from 20 – 30 lux to 500 lux (100%) and CCT from 2700 K to 4000 K
- Control mechanism:
  - Within 10 min dimming
  - Staying 40 min in relaxing mode
  - Followed by a 10 min increase back to biodynamic curve

Scenes (TV)

Watching TV is beside reading and social activities also an activity that takes place in every-day life of elderly people in care-facilities, hospitals and private homes. Therefore, our lighting system will provide a cosy ambience for this situation. Light levels will be reduced but will be sufficient for identifying the buttons of the controller and the surrounding.

- Direct lighting – down light (task light):
  - Eh_{task} = 50 lux (or direct task light will be switched off if daylight is sufficient) (5%)
  - $CCT_{daytime}$ = 3000 K
  - $CCT_{siesta\&evening}$ = 2700 K (siesta: 12-1.45 p.m., evening: after 8.30 p.m.)
- Indirect lighting – uplight (ambient room lighting):
  - Eh_{room} = 20 Lux (2%), accompanied by Ev = 10 Lux (2%)
  - $CCT_{daytime}$ = 3000 K
  - $CCT_{siesta\&evening}$ = 2700 K (siesta: 12.00-1.45 p.m., evening: 8.30-9.30 p.m.)
  - CCT_{night} = 2200 K (at night after 9.30 p.m. until 7 a.m.)
- Control mechanism:
  - Direct transition into or out of scenes (without delay, no dimming)
  - Back transition to biodynamic lighting within 5 min after 90 min automatically or immediately after manual deactivation

[1] Kujisters A 2014

- If TV scene is active during changing time periods e.g. TV scene was switched on in the late afternoon and is still active when it gets evening, transition from TV scene daytime to TV scene evening happens over 5 min

2.2.2 Expected effects from a lighting concept containing biodynamic lighting and specific interventions (activation, relaxation, TV scene):

- Improvements of circadian rhythms and behaviour (active during phases of wakefulness during the daytime and inactive during sleep phases at night)
- Preparing for upcoming activities (therapy sessions, social activities, going to sleep, resting periods) and improve commitment for these activities
- Improved light conditions for visual information processing considering special visual requirements of elderly people
- Enhanced visual comfort and improved ambient lighting atmosphere due to defined scenes (TV scene)

2.2.3 Norm light

There is the possibility to activate a norm light, if biodynamic lighting is not desired of any reason or if there is an emergency (e.g. in siesta time, when light is dimmed) or any other reason when light is needed immediately. It will provide a good but not bright light for visual efforts fulfilling current standards. Colour temperature varies between day- and nighttime.

Norm light daytime (7 a.m. – 8 p.m.):

- Direct lighting – down light (task light):
    - Eh_{Task} = 1000 lux (100%)
    - CCT = 4000 K
- Indirect lighting – uplight (ambient room lighting):
    - Eh_{Raum} = 600 lux (60%), accompanied by Ev = 300 lux (60%)
    - CCT= 4000 K

Norm light night-time (8 p.m. – 7 a.m.):

- Direct lighting – down light (task light):
    - Eh_{Task} = 300 lux (30%)
    - CCT = 2200 K
- Indirect lighting – uplight (ambient room lighting):
    - Eh_{Room} = < 50 lux (5%), accompanied by Ev <50 Lux (10%)
    - CCT = 2200 K

Transition to biodynamic lighting:

If biodynamic lighting is switched on and norm light will be switched on (overwrites biodynamic), norm light will stay constantly for 30 minutes. After 30 minutes the system will turn back to biodynamic lighting via dimming (to avoid that norm light will be switched on for the rest of the day) = automatic transition norm light – biodynamic lighting.

If biodynamic lighting is switched on and norm light will be switched on and again off, the system dims directly within one minute back to biodynamic lighting = manual transition norm light – biodynamic lighting.

If biodynamic lighting is deactivated, which means only norm light was turned on, the system maintains in norm light mode until biodynamic lighting is manually turned on. The transition will be performed directly within 1 minute.

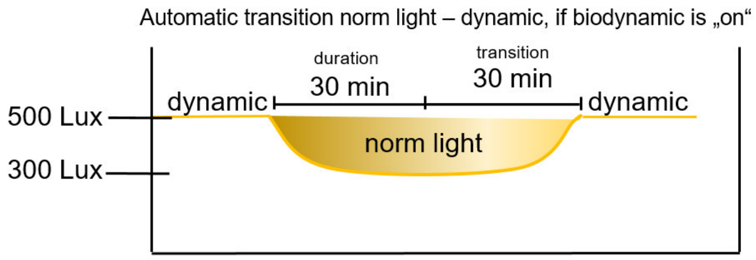


Figure 7: Course of the automatic transition from norm light back to biodynamic lighting, if biodynamic lighting is turned on

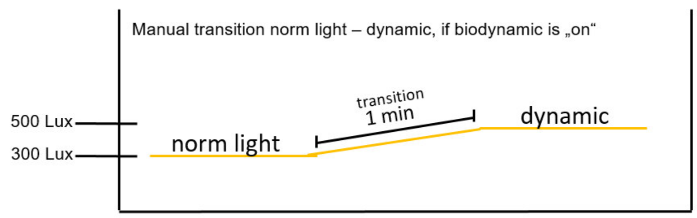


Figure 8: Course of the manual transition from norm light to biodynamic lighting, if biodynamic lighting is turned on

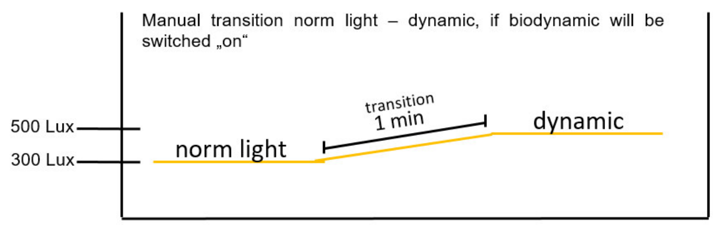


Figure 9: Course of the manual transition from norm light to biodynamic lighting if biodynamic was turned off and now will be turned on

2.3 Hardware: The GREAT Luminaire

2.3.1 Optical Concept

To develop an adequate luminaire we are bound by the requirements detailed in Section 2.1 and the minimum requirements to reach the goals set by the project.The two main parameters when developing the optical concept for the GREAT luminaire were the maximum luminance of 1000 cd/m² in the person's field of vision and the target vertical illuminance at eye level (E_v) of 500 lx (see Figure 10).

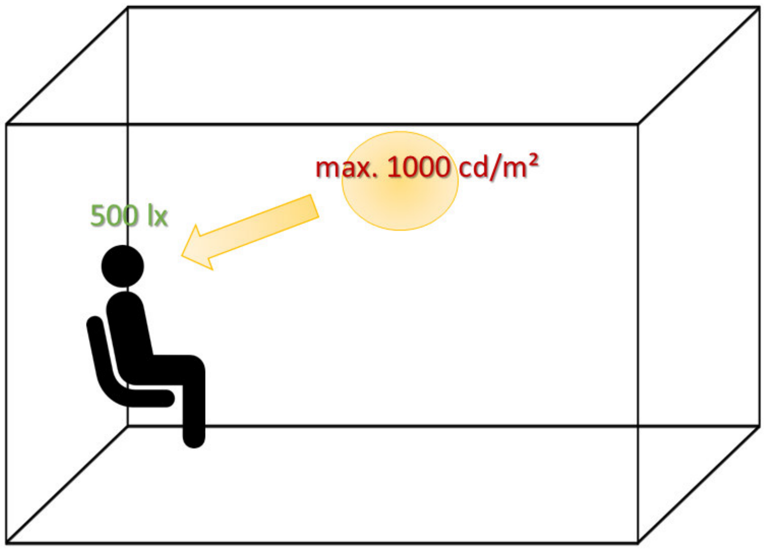


Figure 10: Sketch of room with target illuminance and luminance restriction for the luminaire

As point sources such as LED possess several million cd/m² we need to use an optical system that reduces the glare, e.g. a diffuser that extends the size of the light source. However, since we have very high requirements for the E_v we had to make a detailed photometric study (Figure 11). When assuming a size of 0.5 m² for the luminous area of the luminaire we will reach only about 100 lx[2]. To achieve E_v = 500 lx the luminous area would have to be more than 2 m², which is not really suitable for a luminaire.

[2] assuming a distance of 1.4 m and an angle of ca. 30°

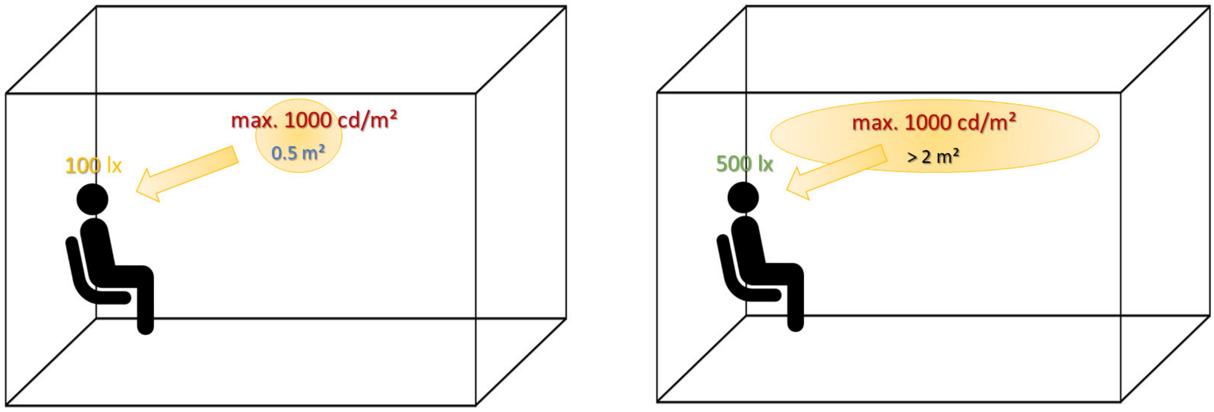


Figure 11: Sketch showing the E_v when assuming a luminaire size of 0.5 m² (left) and the luminaire size (> 2m²) when we want to reach the target E_v of 500 lx

The GREAT luminaire uses and indirect approach for the illumination where the light is directed upward and the ceiling acts as a reflector (Figure 12). In that way, the luminous area is greatly enlarged and much larger luminous fluxes can be used while the luminous density in the field of vision will not reach more than 500 cd/m². In that way it is possible for the GREAT luminaire to reach an E_v of 400 lx.

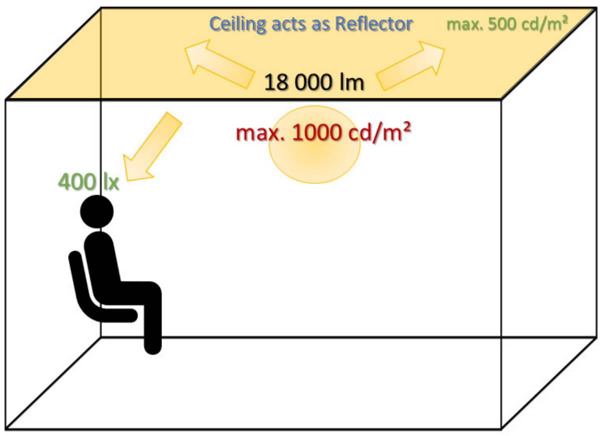


Figure 12: Indirect illumination concept for the GREAT luminaire (Uplight)

By combining this indirect "Uplight" with a smaller diffuse panel and Spots for task lighting the target E_v of 500 lx can be reached as well as a task illuminance (horizontal) of 1000 lx ("Downlight"), as shown in Figure 13.

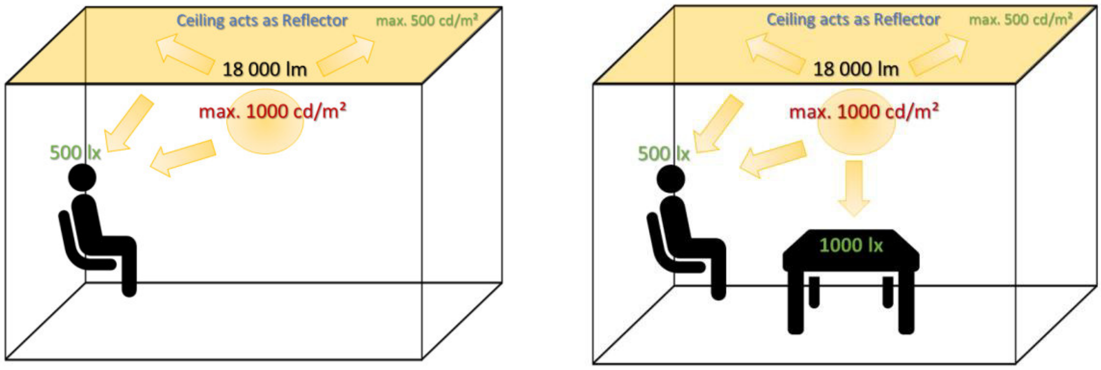


Figure 13: Increasing the vertical illuminance by adding a diffuse panel to the luminaire (left) and reaching high horizontal illuminances by adding task lighting by spots (right)

Table 2 shows the advantages and disadvantages of diffuse and task lighting. By combining the two approaches we can not only combine the positive properties of each lighting concept, but also reduce the disadvantages such as light pressure. This knowledge was generated in the research project "CommONEnergy" by Bartenbach (Figure 14).

Table 2: Advantages and disadvantages of diffuse and task lighting

Diffuse Panel	Task lighting
+ no radiation pressure + flexible usage (e.g. dining table, bedroom) + increases vertical illuminance	+ excellent task lighting
- no increased task illuminance - limitation of the light flux by luminous density	- no increased vertical illuminance - radiation pressure - risk of glare - multiple shadows

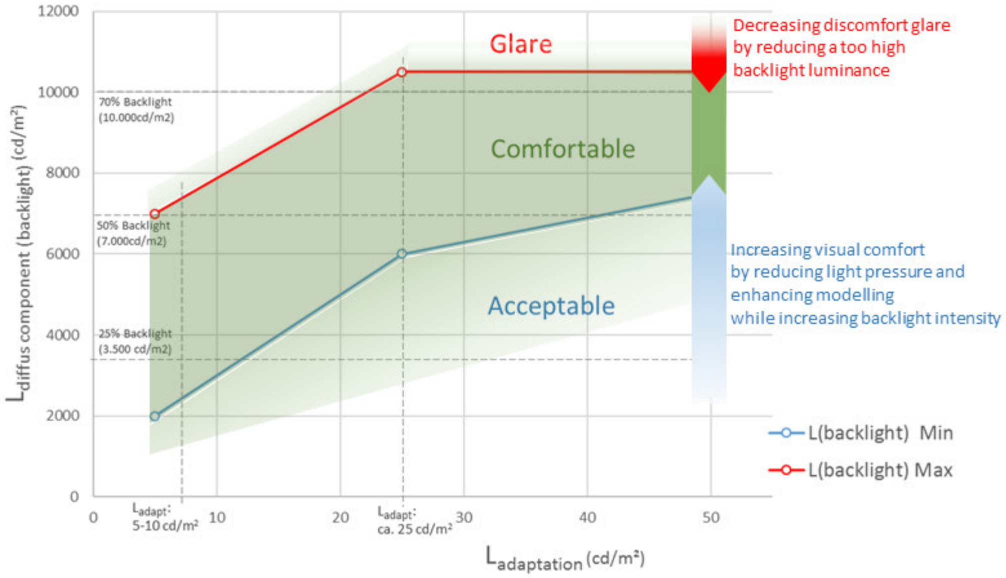


Figure 14: Results of light pressure study

The finalized lighting concept as developed by *Bartenbach* now combines an indirect component ("Uplight"), where most of the luminous flux is emitted and that is responsible for generating the lion's share of the E_v needed to invoke the biological effects intended by the project with a "Downlight" that combines a luminous panel for additional E_v and Spots for task illumination. The Luminous Intensity Distribution (LID) for the GREAT luminaire can be seen in Figure 15.

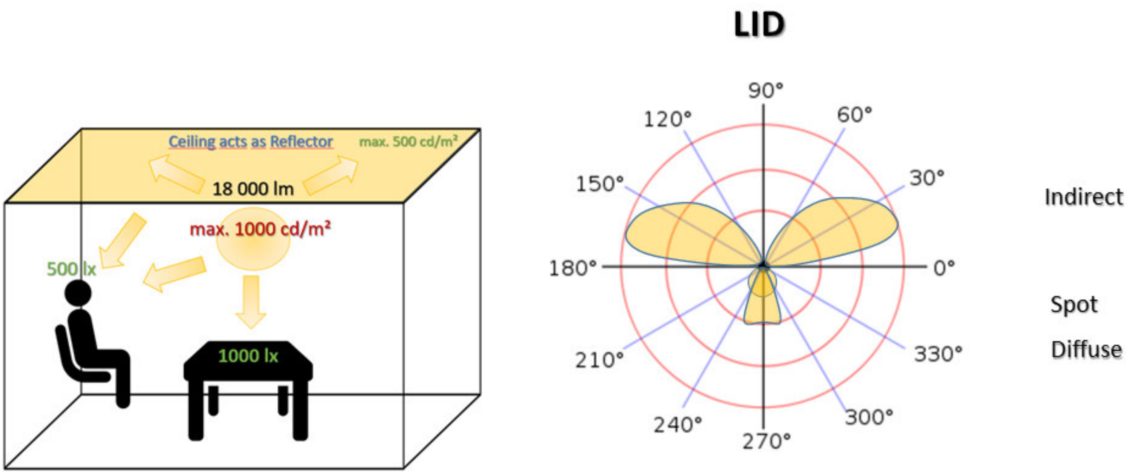


Figure 15: Finalized lighting concept for the GREAT luminaire

2.3.2 Optical Design

BB and EMT worked together on the implementation of the optical design in the luminaire.

2.3.2.1 Uplight – Concepts

Reflector Concept

A first approach in the development of the GREAT luminaire was to use BB's own components RDB or RDB-DW, which were designed as wall washers but could in this function also be used to flood the ceiling.

The design including the RDB-DW, a wall washer that also includes a downlight component. In an upside-down mounting as in the case of the ceiling washer this part of the light will go out horizontally. The idea was to mount the single reflectors in a ring to flood the ceiling evenly in all directions and to "catch" the horizontal share of the light with a diffuser to create a luminous ring around the luminaire (Figure 16). However, this idea was not feasible in reality because the luminous density of the diffuser would reach about several thousand cd/m².

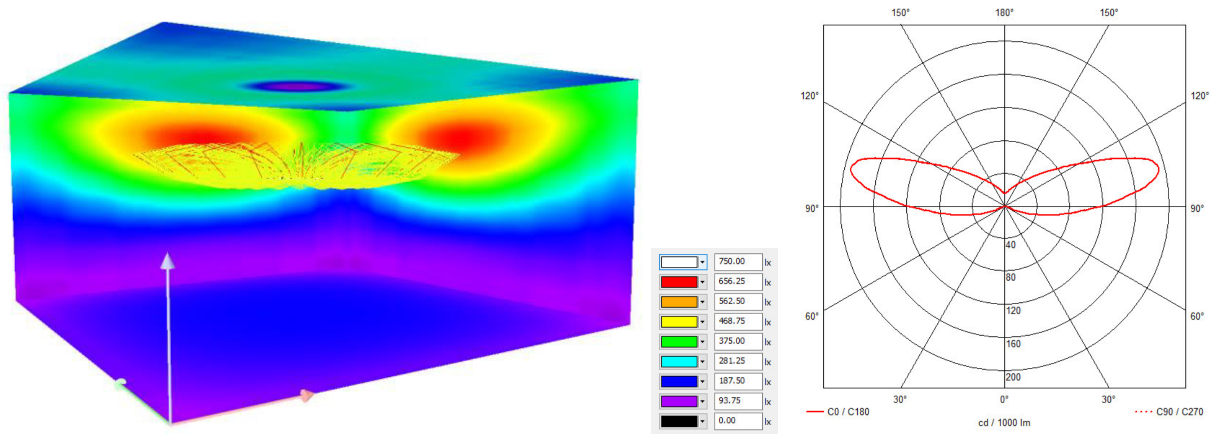


Figure 16: Concept with RDB-DW mounted as a ring. Dialux-Simulation showing the expected illuminances (left) and the simulated LID (right)

A second concept with the reflector RDB was developed. Here, a major focus was the positioning of the luminaire inside the room. For illuminations of large rooms from the middle of the room a ring as shown in Figure 16 is very well suited. However, as in the GREAT project the luminaire should be usable in both care facilities and private settings with very different architecture and furnishing the challenge is to design a luminaire that fits as many situations as possible. Therefore, a ring luminaire is not considered applicable in this project.

For the concept with the RDB a linear, modular design was found. The luminaire would be split into two parts, either opposite each other and illuminating the ceiling in both directions (Figure 17, left) or next to each other illuminating the ceiling in the same direction towards the middle of the room (Figure 17, right).

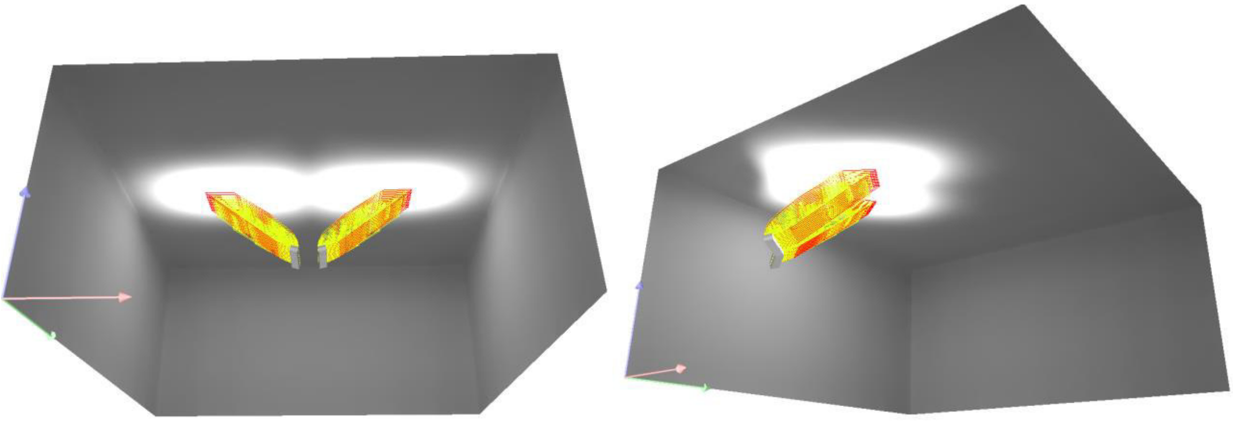


Figure 17: Linear concept with the reflector RDB as a pendant luminaire situated in the middle of the room (left) or the corner of the room (right)

However, this approach has a few disadvantages due to the RDB reflector, which possesses a very sharp cut-off. A softer light distribution on the ceiling would be better, especially when having in mind that the luminaire should be suited for many different rooms. Therefore, an alternative was developed.

Black Box Concept

The final solution used as Uplight for the GREAT luminaire was developed by BB as a low budget solution. Since no high quality reflectors are needed for this solution but only standard materials and a small amount of a scatter gloss material the production costs can be kept low.

The optical concept is shown in Figure 18. A printed circuit board (PCB) with LEDs is placed on a scatter gloss material (MIRO-SILVER 20 | 2000 AG). Light emitted from the LEDs will be reflected diffusely from the scatter gloss material and a broad light distribution in the forward direction is reached.

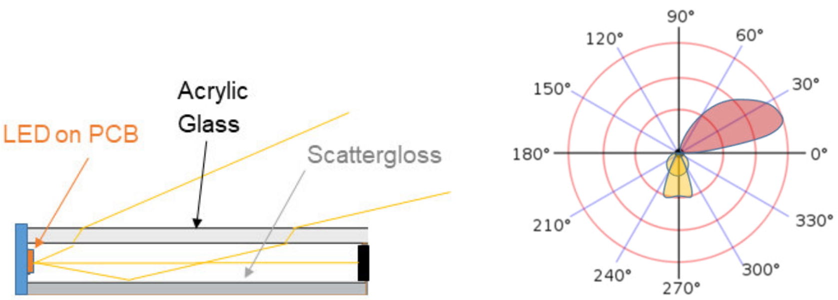


Figure 18: Black Box Concept for the GREAT Uplight (left) and the LID in red (right)

60 CREE XQE-HI LEDs with 2200 K and 5700 K alternately are placed every 8 mm onto the PCB (Figure 19). The luminous flux of the LEDs is about 10200 lm and the efficiency is

estimated to about 75% from LucidShape Simulations. One relevant issue here is the Colour-over-angle of the LEDs. The CREE XQE-HI was the only LED that was available in 2200 K and possessed an acceptable Colour-over-angle to our knowledge. Furthermore, it was important for the LED to be as small as possible to achieve a high efficiency, so other LEDs (e.g. Nichia x48) were not suitable for usage.

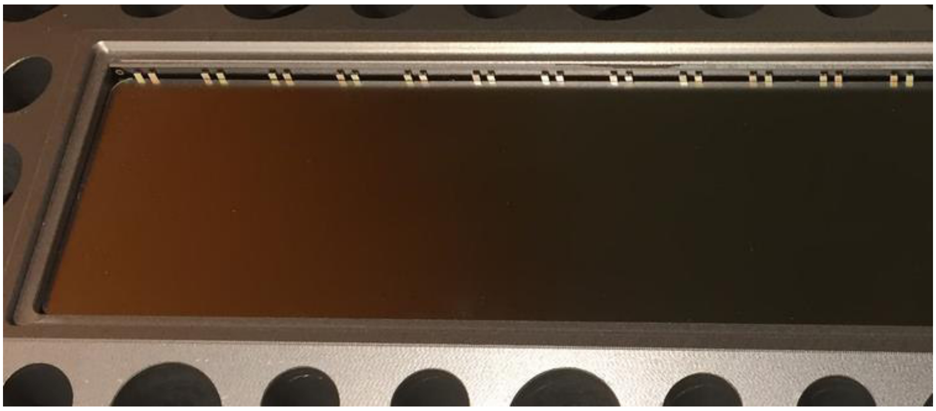


Figure 19: Photo of the Uplight of the GREAT luminaire

The warm white LEDs with 2200 K and the cold white LEDs with 5700 K can be controlled separately. Furthermore, temperature measurement was integrated to guarantee a stable thermal environment for the LEDs. The maximum power for the Uplight module is 110 W.

In Figure 20 the Dialux simulation for the GREAT Uplight in a 25 m² large room can be seen. One can see that the light distribution in the room is quite homogenous and high illuminances are generated over a large room area.

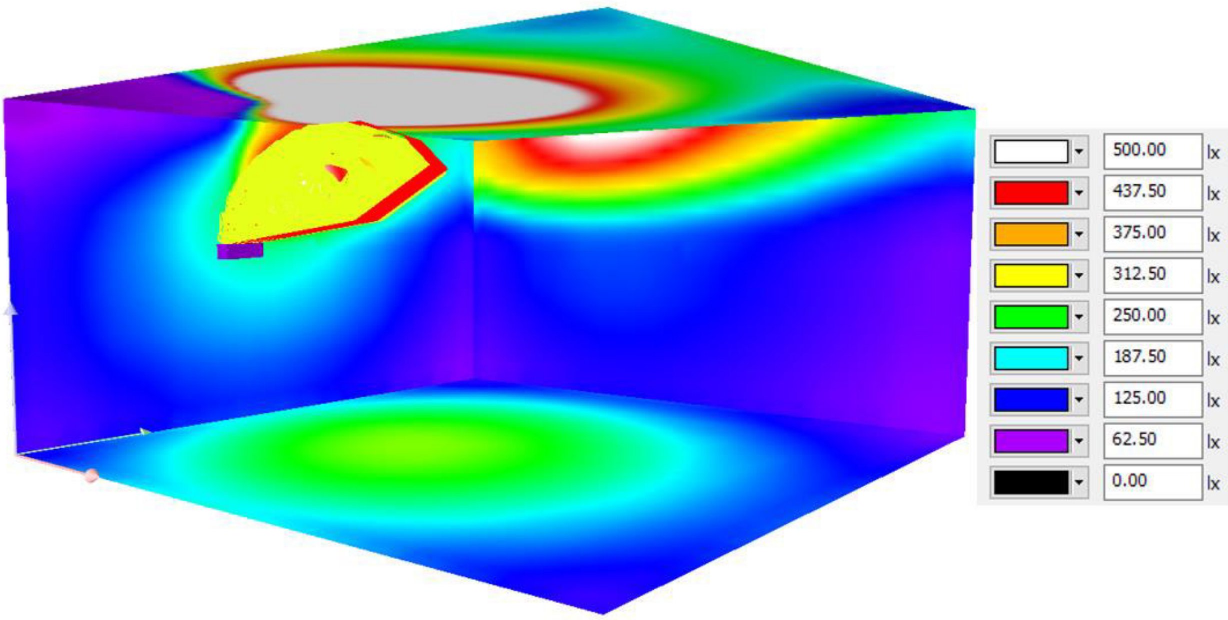


Figure 20: Dialux simulation of the GREAT Uplight

2.3.2.2 Downlight

As already explained in Section 2.3.1, the addition of a diffuser adds E_v to our luminaire and the integration of spots generates a high level of task illumination.

For the diffusor a 15 mm thick ideal diffusor material was used with a transmission of 45% and with an area of 0.15 m². 70 Luxeon 3014 low power LEDs with 2200 K and 5700 K have been used for the backlighting, generating approximately 600 lm.

The task illumination is generated by three LFO lenses by Bartenbach each one lit by 4 CREE XQE-HI with 2200 and 5700 K generating about 1800 lm. The spots and the diffusor can be controlled separately so there is no issue with glare, e.g. in clinics with bedridden patients.

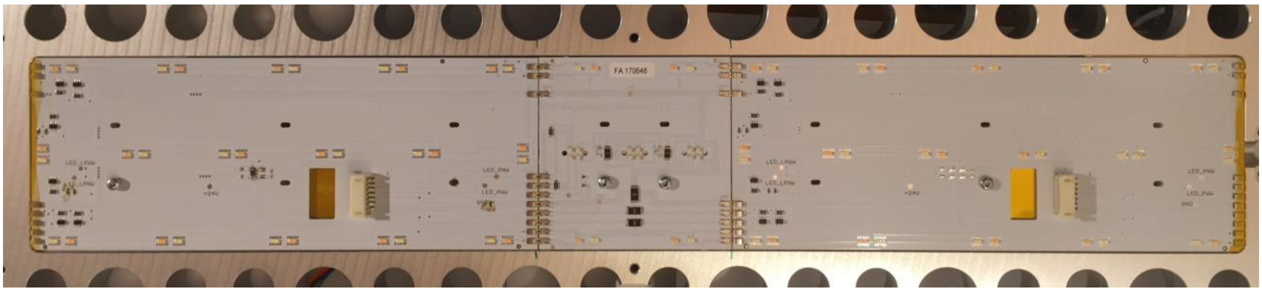


Figure 21: PCB for the Downlight

In Figure 22 the expected illuminances by the GREAT downlight can be seen in a Dialux simulation. One can see that a quite even distribution with more than 1000 lx in the working plane.

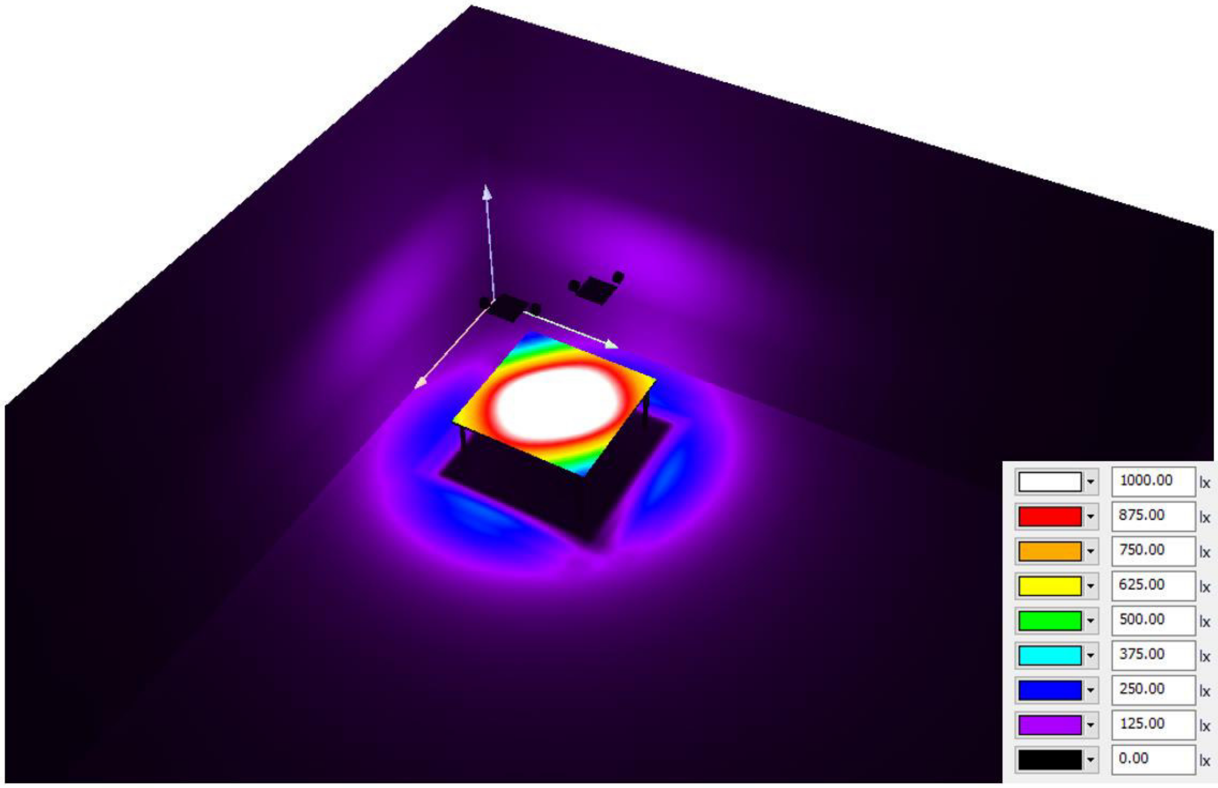


Figure 22: Dialux Simulation for the GREAT Downlight

2.3.2.3 Total Luminaire

In Figure 23 the light distribution of the GREAT luminaire is shown as well as the isolines for the horizontal illuminance at the working plane. One can see that a large part of the room (25 m^2) is illuminated very well with the targeted horizontal illuminance.

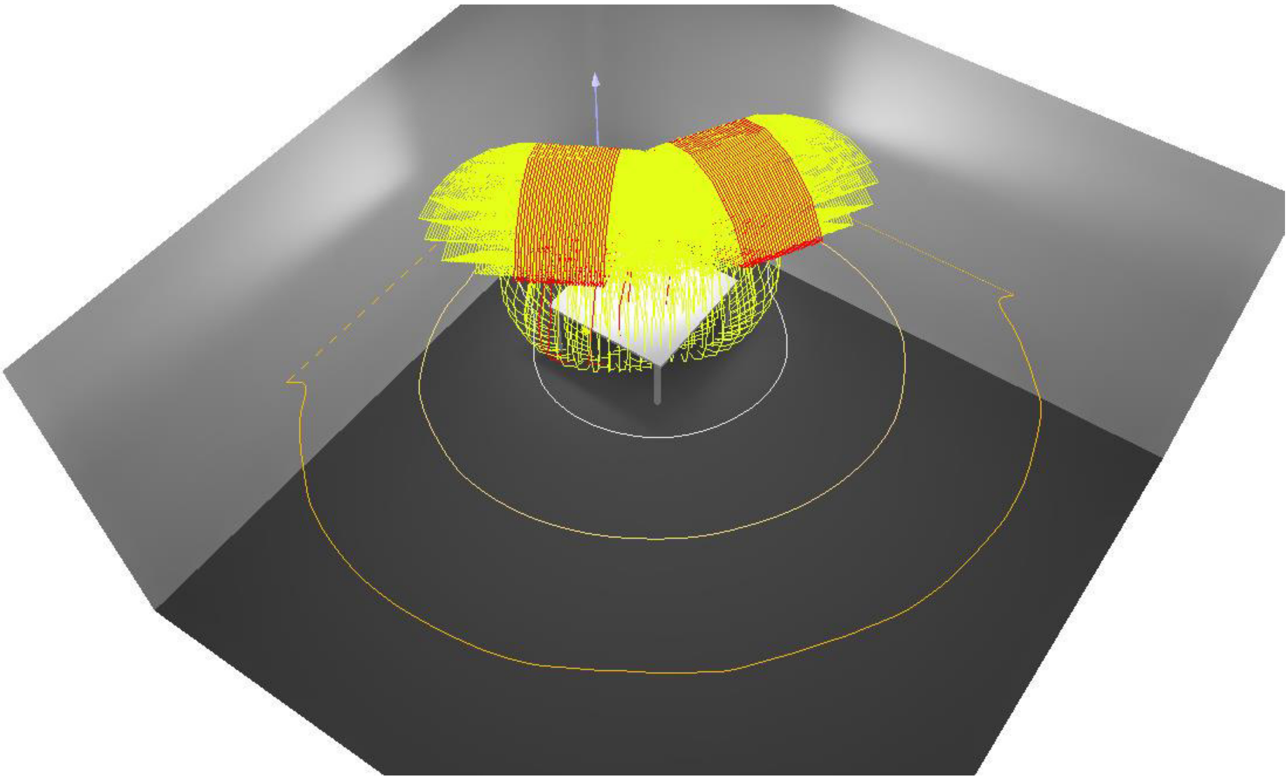


Figure 23: Dialux Simulation of the light distribution of the GREAT luminaire. Also shown are the isolines for 200 lx (orange), 300 lx (yellow) and 500 lx (grey).

Figure 24 and Figure 25 show Dialux simulations with the illuminances and luminances in the room of the GREAT luminaire.

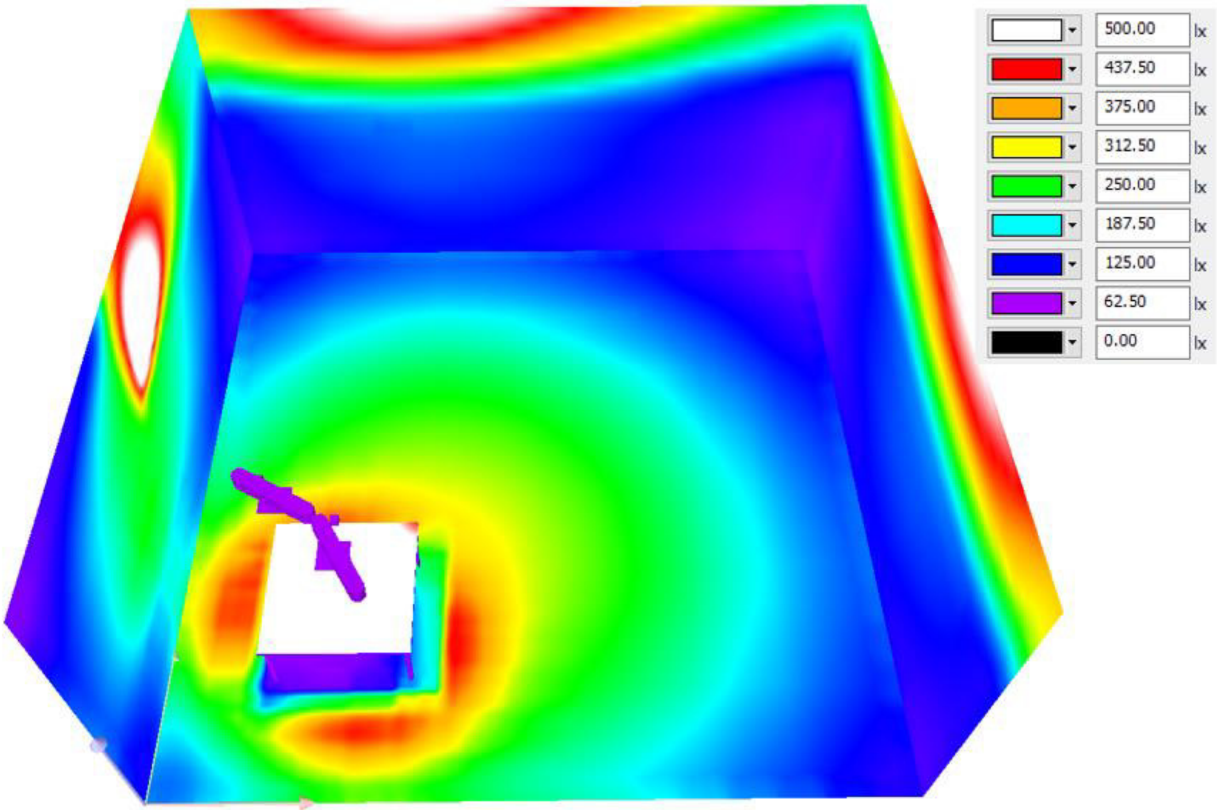


Figure 24: Dialux simulation of the GREAT luminaire showing the illuminances in a 25 m² room.

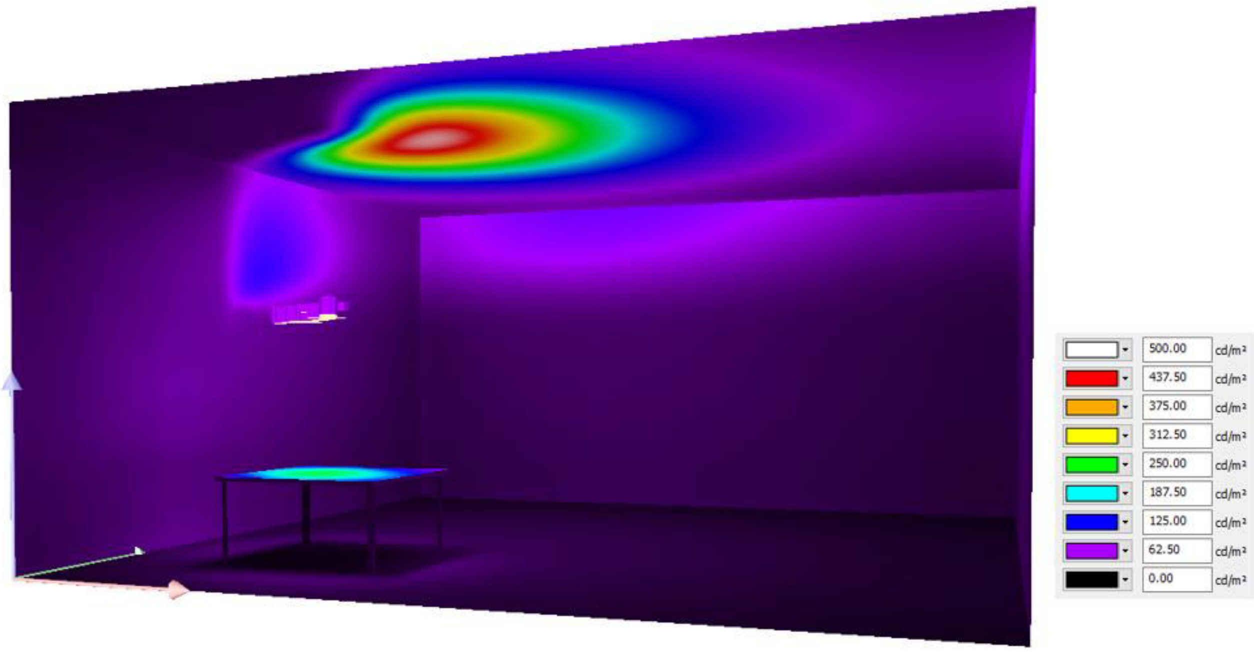


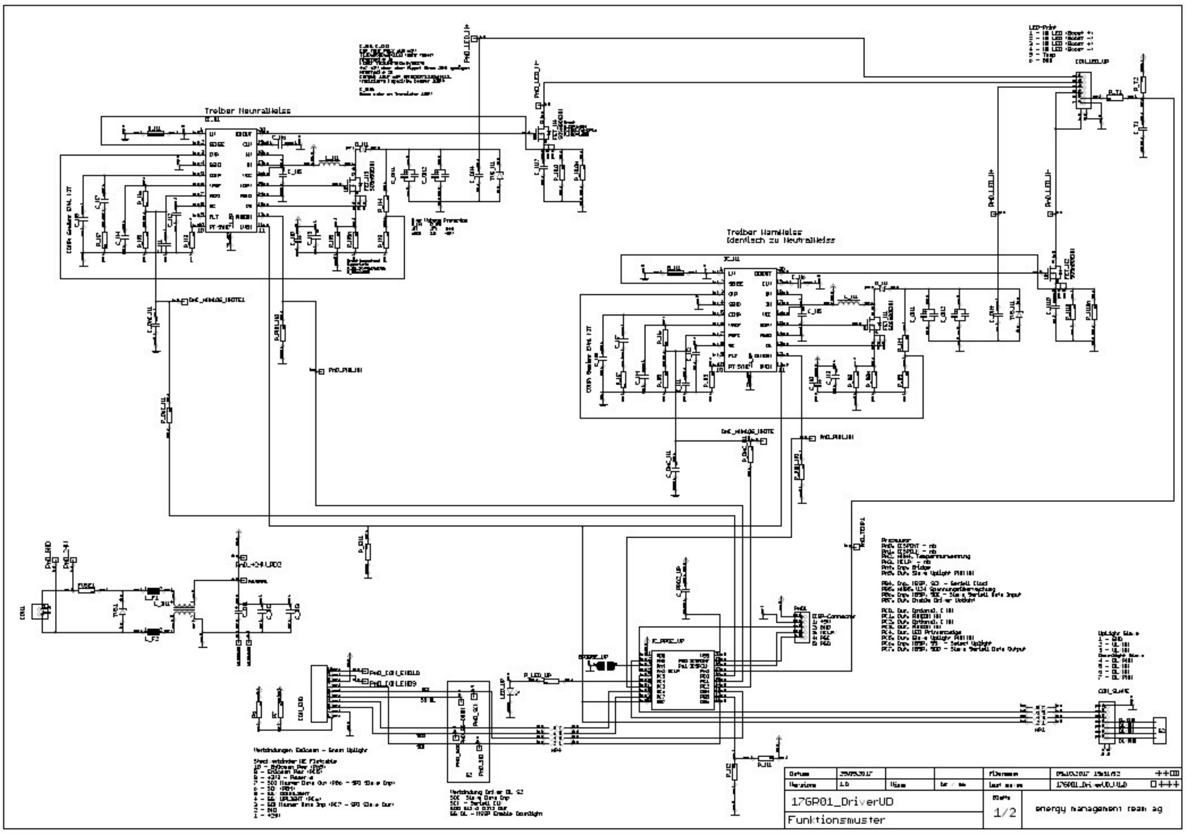
Figure 25: Dialux simulation of the GREAT luminaire showing the luminances in a 25 m² room.

2.3.3 Electronic Design

The electronical implementation was up to EMT. EMT developed a driver board (Figure 26 and Figure 27) to control the LEDs and a radio board based on EnOcean (Figure 28 and Figure 29) to communicate with the central controller. Single driver circuits were defined and calculated matching the power of each LED strand.

Driver pcb:

- Uplight: 2 High Power Boost Driver with high frequency pwm and analoge controlling possibilities. Each has >50W power possibilities.
- Downlight: 2 High Power Boost Driver with PWM and 2 low power driver
- 2 microprocessors for up- and downlight controlling
- Possibilites controlling other light engine as a *slave*
- SPI communication with master rf device
- Integrated switching power supply for low power consumption



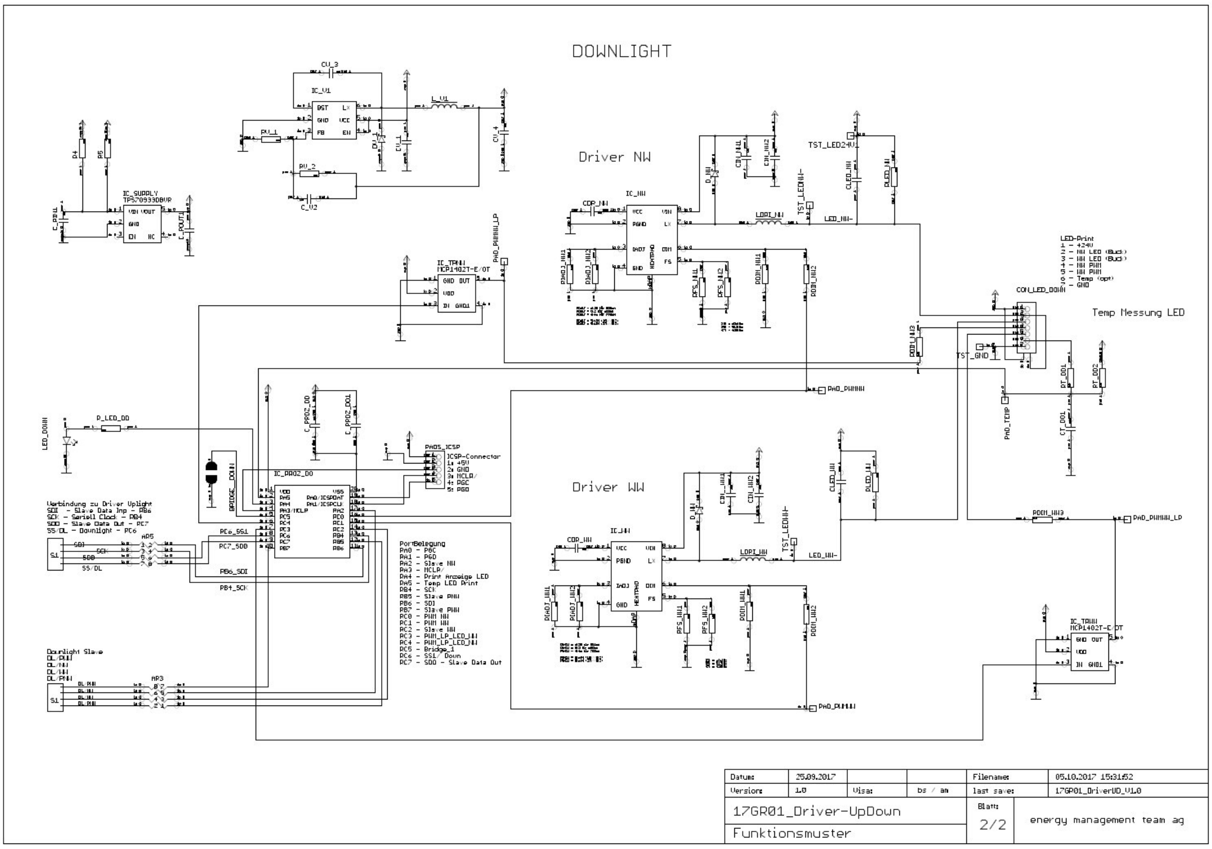


Figure 26: Driving board scheme for controlling Up- and Downlight

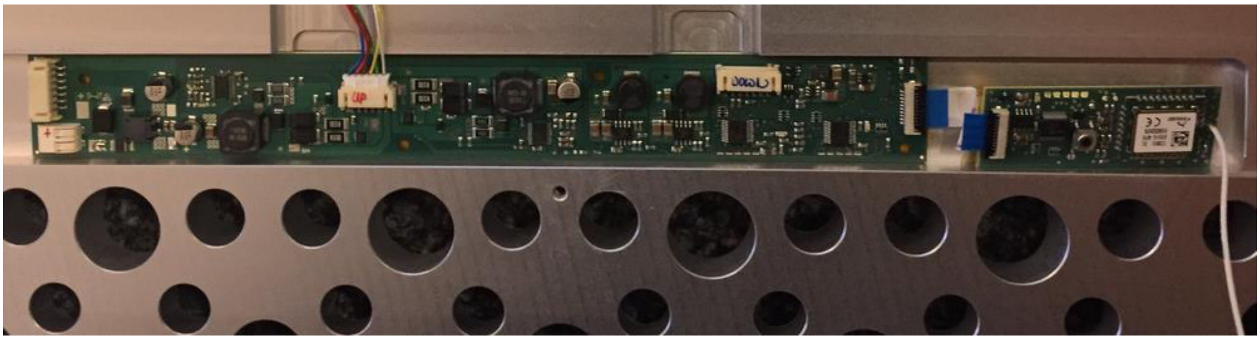


Figure 27: Build-in driving board for controlling Up- and Downlight

Encean pcb:

- EnOcean controller and microprocessors
- SPI communication with driver pcb
- Learning possibilities realised with hall sensor and mechanical switch on pcb

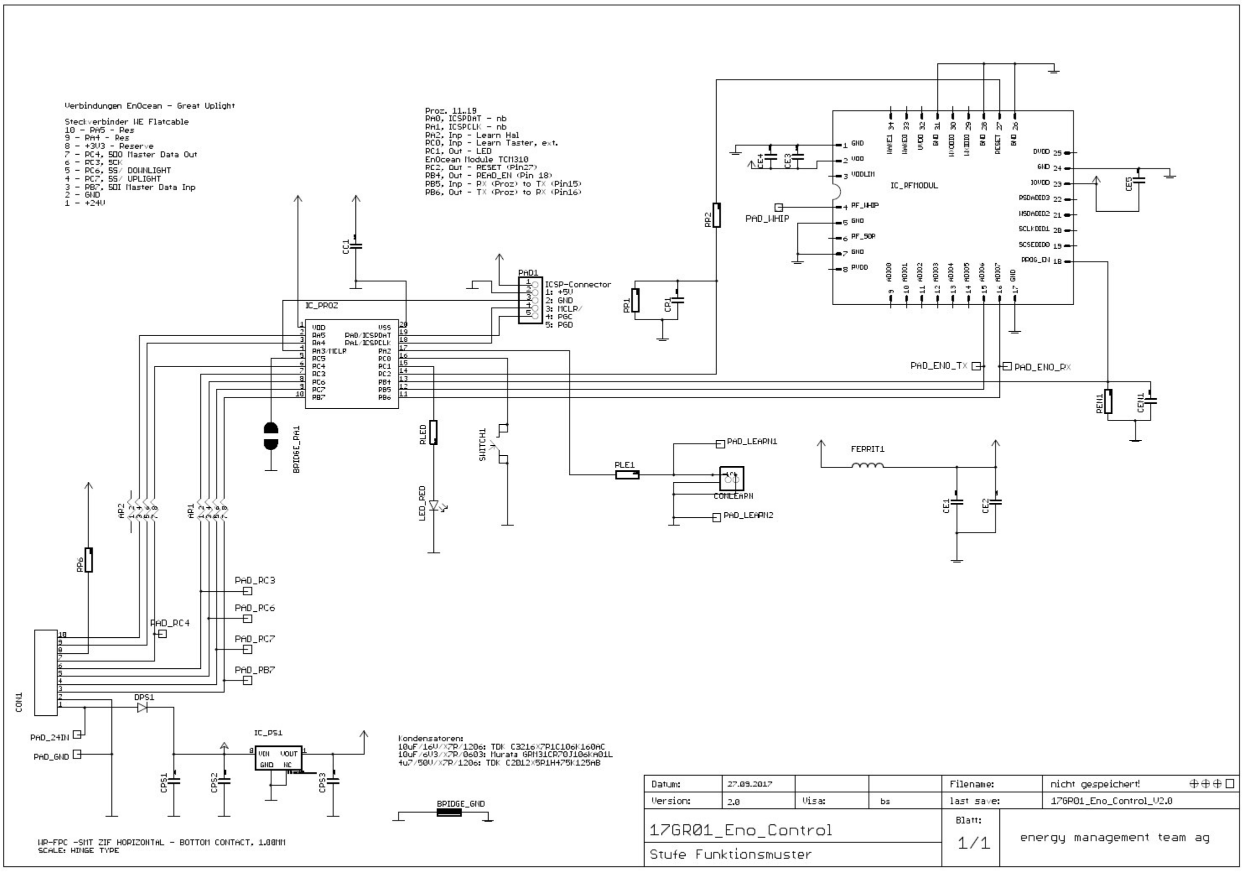


Figure 28: EnOcean scheme master board

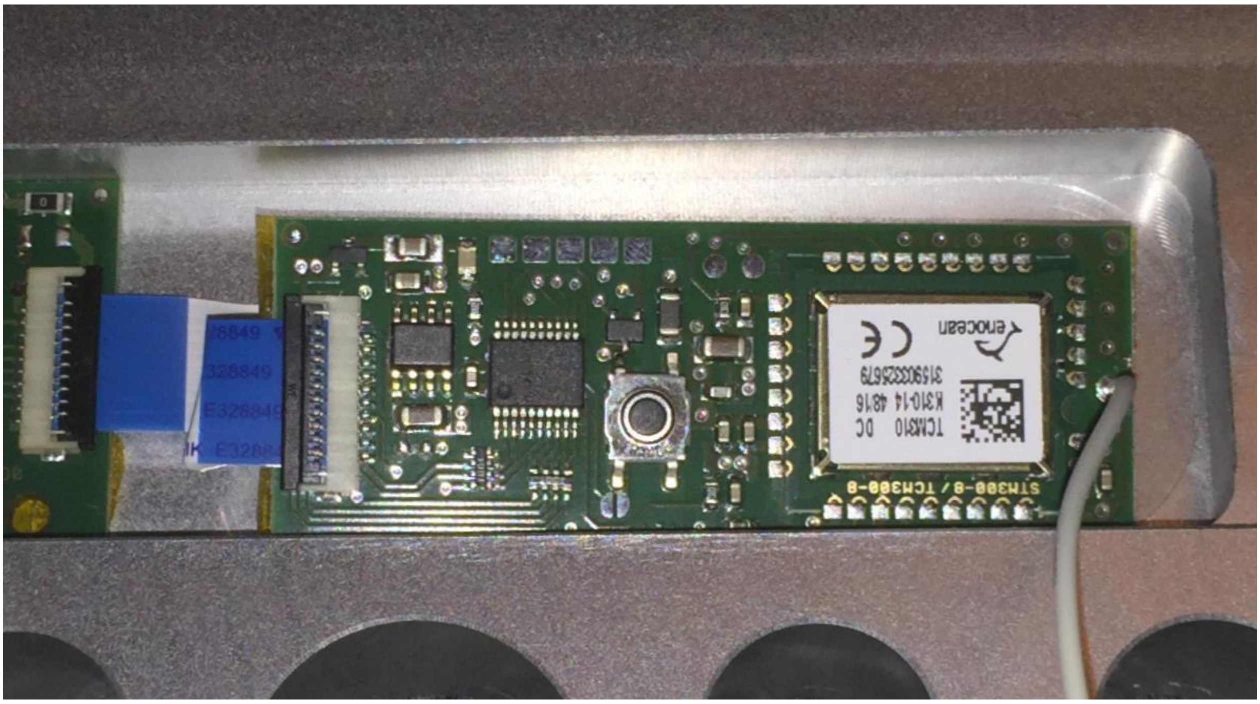


Figure 29: EnOcean communication circuit board for controlling Up- and Downlight

2.3.4 Microprocessor Software

The developed software encounters 3 microprocessors for each luminaire. 2 processors control the Uplight- and Downlight LED:

- Communication with EnOcean master
- Control driver for warm white and neutral white LED
- Control of temperature and other functions

For the communication between luminaire and controller a protocol matching the project needs was developed. It is based on an EnOcean standard profile.

Furthermore, following master functions were implemented:

- Learning mechanism, which allows teaching to a specific controller
- Additional possibilities to test and configure the luminaire

2.3.5 Mechanical System and Design

In cooperation with *entux* (subcontracting of emt) the luminaire was designed. Subsequently, 4 prototypes of the luminaire were commissioned for the functional tests (Figure 30).

Figure 30: Standing luminaire «GREAT»

2.3.5.1 Design phase

entux presented 4 different possible designs. The design „Aussparung – Loch“ (Figure 31) was chosen by Bartenbach and EMT. At this time, we considered first drafts for implementing a standing luminaire.

Figure 31: Evaluated design concept

2.3.5.2 Technical design – arrangement phase

The chosen design draft was further elaborated and implemented. The cooling element took great efforts (Figure 32) and was finally made of milled Alu-parts (Figure 33).

Recesses:
Beside the main corpus on both sides.
Put in and screwed together.
Variants:
-pressure casting aluminium corpus
-extrusion presses
-milled parts
-sand casting

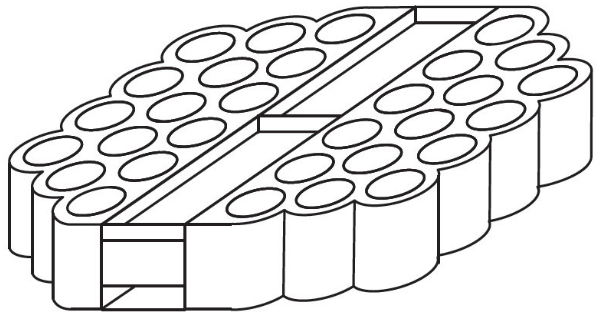


Figure 32: cooling element - concept

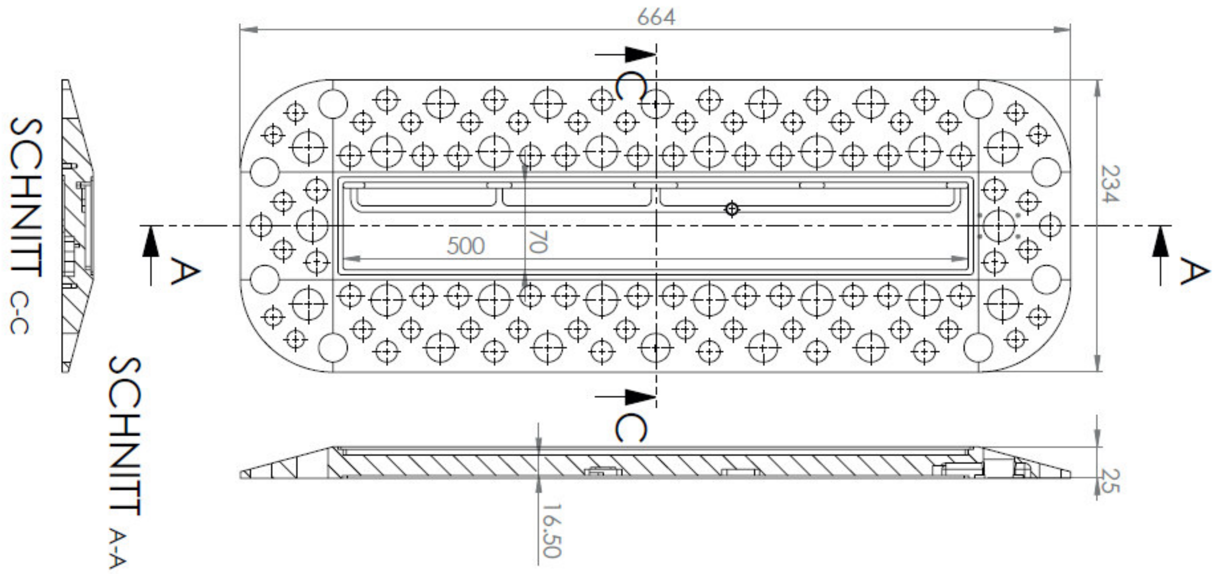


Figure 33: cooling element – realized milled part of Alu

3 Sound Module

3.1 Basic Considerations

Today ultra sound is used in a wide range of products, starting from mosquito repellents ranging to distance sensors in parking assistance systems. Also in bats research, products for measuring of and playing back ultra sound signals are used. One major downside of these products, however, is that they are either limited to a very narrow frequency band or they lack the capability to reproduce also audible sounds at a satisfying (even recognizable) quality.

In the upper range of HIFI systems, speakers with sound reproduction capabilities of up to 100kHz are available, however, the price range of such systems (thousands of Euros) is not in the realm of an affordable system like envisioned for GREAT (the sound prototype should cost max. 150 Euros).

However, even low cost speakers can reproduce ultrasound at certain frequencies (see the section Measurement of Ultrasound Characteristics Logitech Z150 below).

This led to the idea, to base the sound module on relatively affordable active speakers combined with a high quality digital analog converter to feed the audio signal. Standard music file formats can be used to save stimuli materials. With a sampling rate of 192kHz, information of signals up to a frequency of 96kHz can be reproduced. On the software side, only a remotely controllable music player would be required. For this project, the Logitech Z120, Z150 and Z200 have been evaluated. Due to size and price point, and basically the same ultrasound reproduction characteristics as the Z200, the Z150 speakers have been selected for the first prototypes.

3.2 Measurement of Ultrasound Characteristics

To determine the characteristics of the ultra sound distribution capabilities of the Logitech Z150 speakers, test measurements have been performed in the noise isolated audio lab of the FHV. For this, a test audio sequence with sinus modulated signals in 5kHz steps ranging from 20kHz up to 95kHz has been assembled. The ultra sound audio signal has been measured by a Avisoft Bioacoustic UltraSoundGate 116H recorder at predefined points in the room (see Figure 34).

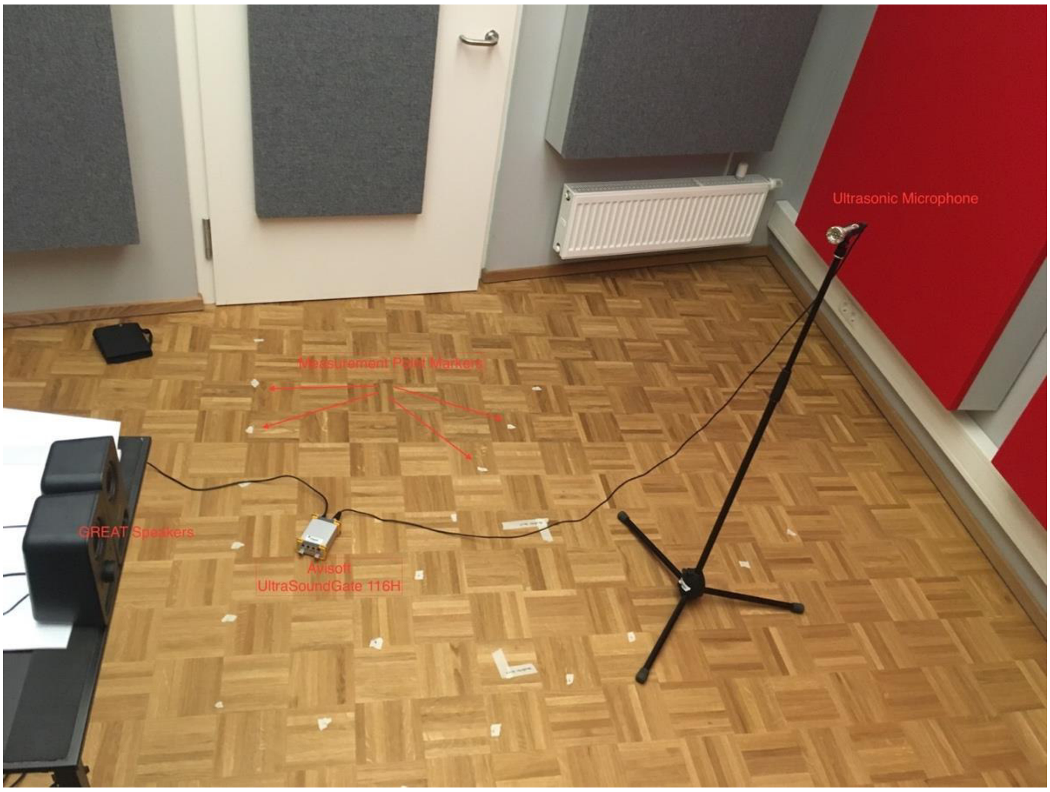


Figure 34: Sound measurement setup in Audio-Lab at FHV.

For this, multiple points in 25 cm distances ranging from 25 to 200 cm for 0, 30, 60, and 90 degree angles have been measured. During the measurements, the height of the microphone and the Z150 speakers have been held constant at the same level, which was 1m above the floor.

The results show the expected quick drop-off of the ultrasound signal with increase of frequency, distance, and/or angle from the middle axis of the speakers (see Figure 35). The frequency reproduction quality is not continuous in the ultrasonic range. Some frequencies can be reproduced at a better quality (e.g. 25 kHz,45 kHz, 75kHz – see Figure 36) than others, which was an expected outcome (otherwise speakers would be rated as ultra-sonic capable). However, for the testing prototype these characteristics are acceptable, as sounds can be optimized within certain limits to use those frequency bands, that are better reproduced. Furthermore, the sound stimuli do not only contain ultrasonic but mainly audible frequencies as their main component, which are reproduced well.

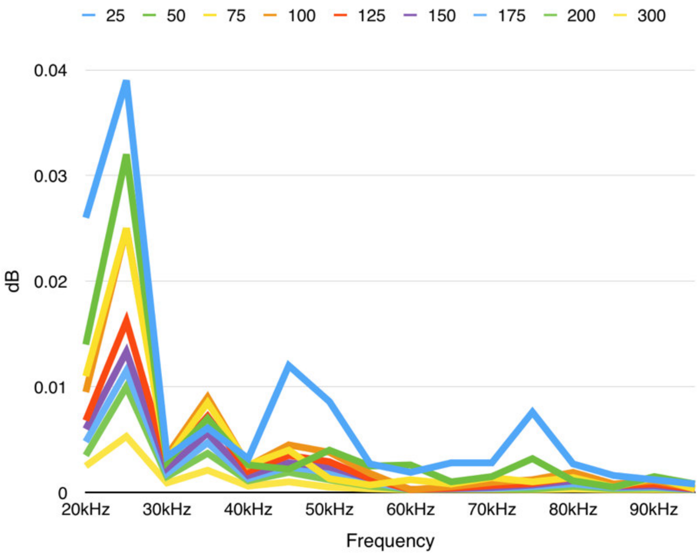


Figure 35: Drop-off of signal level depending on frequency and distance

Figure 36 shows the measured strength of the specific frequency at different distances and angles. Green values indicate an acceptable signal reproduction, red values indicate a weak frequency differentiation and therefore mark not effective locations/frequencies for ultrasonic exposures.

Entfernung cm	Winkel	20kHz	25kHz	30kHz	35kHz	40kHz	45kHz	50kHz	55kHz	60kHz	65kHz	70kHz	75kHz	80kHz	85kHz	90kHz	95kHz
25	0	-28.5	-24.9	-45.9	-41.5	-46.8	-35.1	-38.1	-48.3	-50.9	-48.1	-48.1	-38.9	-48.4	-52.7	-56.3	-60.3
25	30	-34.9	-29.7	-67.7	-45.5	-49.5	-43.6	-47.5	-48.6	-50.4	-52.6	-50.0	-54.2	-58.7	-59.1	-50.1	-64
25	60	-49.5	-43.2	-43.8	-48.6	-51.4	-49.9	-57	-43.5	-45.3	-62.3	-56.2	-56.5	-49.3	-54.2	-51.5	-66.5
25	90	-51	-38.9	-64.3	-62.4	-62	*-87.5*	-51	-53.6	-61.5	-56.7	-54.3	-65.7	-77.4	-56.9	-67.2	-72
50	0	-33.7	-26.6	-47.3	-40.2	-48.5	-50.1	-44.7	-49	-48.5	-57.3	-53.7	-46.8	-56.9	-63.6	-53.7	-60.1
50	30	-43.7	-35.6	-51.1	-47.4	-59.6	-53.2	-50.9	-50.8	-69.8	-68.1	-60	-59.2	-57.5	-54.6	-69.9	-76.1
50	60	-53.2	-42.2	-58.3	-52.1	-55.6	-58.9	-58.6	-55.3	-54.9	-61.7	-62.8	-56.8	-59.5	-68.4	-65.4	-69.1
50	90	-59	-45.9	-65.5	-65.9	-73.9	-76.2	-56.2	-63.1	-66.4	-65.5	-60.8	-75.1	-72.7	-60.4	-69.9	-77.6
75	0	-35.9	-28.7	-46.7	-38.5	-48.5	-44.7	-54.6	-61.6	-55.6	-59.3	-54	-57.1	-54	-63.7	-54.4	-72.9
75	30	-48.4	-40	-54.9	-50.3	-61.6	-57.7	-53.3	-55.1	-68.0	-67.4	-62.8	-60.7	-62	-57.3	-63.4	-70.3
75	60	-50.1	-45.5	-59.5	-56.8	-60	-59.5	-59.2	-58.4	-59.2	-66.7	-68.4	-60.5	-61.6	-66.1	-71.2	-74.4
75	90	-64	-51	-69.7	-69.9	-81.1	-75.5	-59.6	-68.4	-71	-72.4	-64.3	-81.1	-80.9	-64.9	-81.1	-82.5
100	0	-37.1	-30.4	-45.6	-37.9	-48.8	-43.6	-45.2	-52.3	-83	-63.3	-57.5	-55.4	-51.3	-58	-56.5	-68.8
100	30	-48.4	-43.3	-56.5	-53.2	-63.1	-59.8	-56.2	-58.9	-67.9	-65	-74.5	-59.9	-65.4	-60.5	-65.1	-71.3
100	60	-58.3	-47.6	-64.3	-59.9	-63.0	-66.8	-61.6	-60.2	-60.6	-71.9	-72.1	-63.8	-64.3	-69.6	-72.3	-78.8
100	90	-68.3	-54.9	-68.2	-71.8	-81.9	-76.3	-63.5	-73.3	-75.6	-75.9	-68.5	*-87.1*	-82.4	-68.8	*-87.3*	*-84.7*

Figure 36: Good signal separation (green) and week signal separation (red) depending on distance and angle for different frequencies.

Considering this, we have an expected effective range of ultrasonic exposure of up to a distance from the speakers of 1 m. Therefore, for field tests we recommend to place the speakers as close as possible to the exposure zone (e.g. a relaxing chair). As an example, figure Figure 37 shows the power spectrum of the captured signal at 50 cm distance and 1m distance for 50 kHz and 60 kHz source signals at an angle of 0 degrees, showing a clear frequency differentiation, but also a signal degradation at 60 kHz at a distance of 1 m.

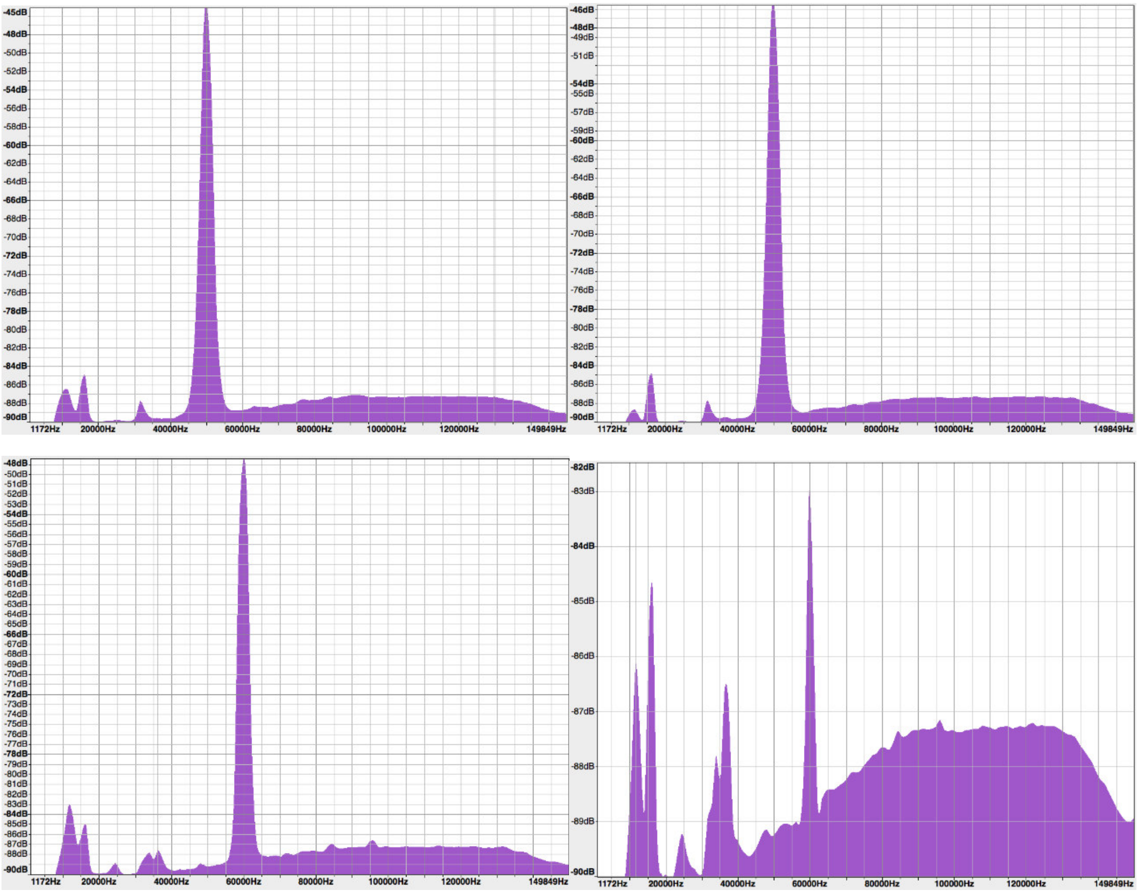


Figure 37: Signal reproduction at distances of 0.5 m (left) and 1 m (right) of 50 kHz signals (top) and 60 kHz signals (bottom).

During field tests, a parallel lab study will be performed with higher end studio speakers (Pioneer RM05), to give more insight into psycho physiological effects of the ultrasound components.

3.3 Hardware

The sound module is based on a Raspberry Pi Zero W module that provides WLAN connectivity. For audio output an IQaudIO Raspberry PiDACZero module is used, offering 192kHz/24bit playback (using a TI PCM5122 DAC offering 32-bit/384kHz). It features a112dB SNR and -93db THD. The DAC is connected via an I2S Interface to the Raspberry to transmit audio signals.

As sound output device, the commercially available Logitech Z150 active loudspeakers are used. They are small enough to integrate into a typical GREAT setting, while still allowing for acceptable ultrasonic capability in this price range (limiting the range to about 1m). They operate on the same 5V level as the Raspberry Pi. Therefore, the sound module only requires one common power supply.

Figure 38: GREAT sound module based on Logitech Z150 active speaker

The Raspberry Pi control board is built into the casing of the Logitech Z150 speakers, resulting in a very compact sound module setup (see Figure 38).

To place the Raspberry Pi Zero and the Pi-DAC Zero safely inside the Logitech Z150 speaker, a holder has been constructed and 3D printed (see Figure 39) for the internals of the sound module, and Figure 40 for a 3D model of the module holder).

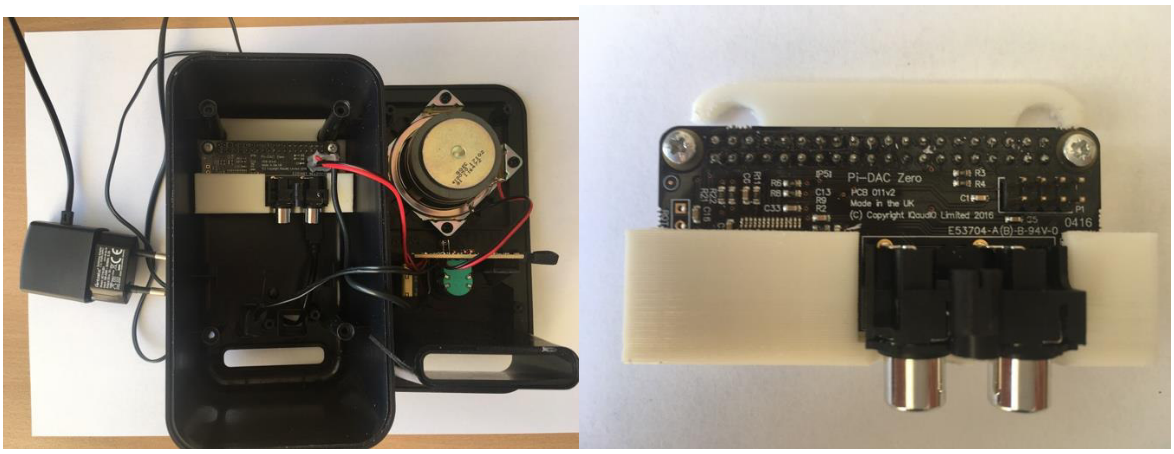


Figure 39: Raspberry Pi and Pi-DAC Zero integrated into the Z150 active speaker.

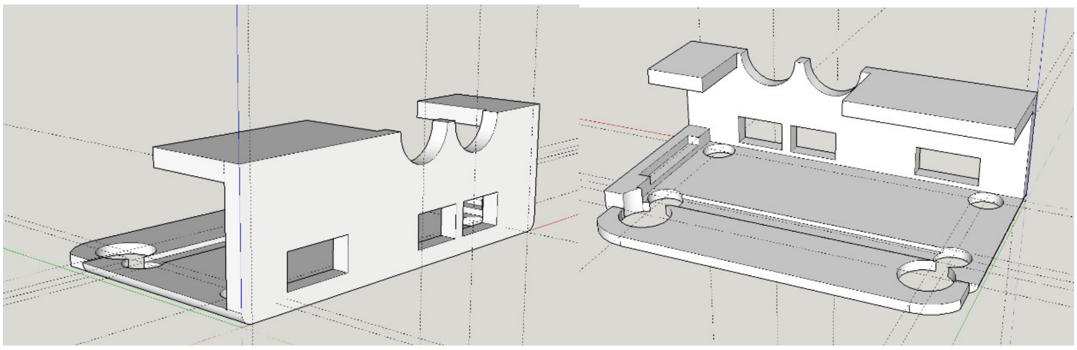


Figure 40: 3D model of Raspberry PI + Pi-DAC Zero holder for mounting inside Z150 speaker

The Logitech amplifier board is connected to the Pi-DAC Zero via the 2x4 header on the Pi-DAC Zero, which provides line-out left/right, as well as GND and a 5V power supply (see Figure 41 for details of the wiring). Note that the original power supply connection is unmounted from the speaker system.

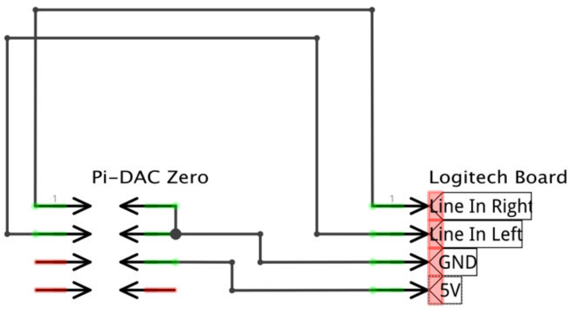


Figure 41: Wiring of the Pi-DAC 2x4 header to the Logitech board inside the speaker.

As an alternative to building the sound module logics into the Z150 speakers, a separate housing has been designed, in case the Raspberry PI and Pi-DAC Zero should be connected to an existing sound system or alternative speakers. Figure 42 shows the 3D model of the case divided into two parts.

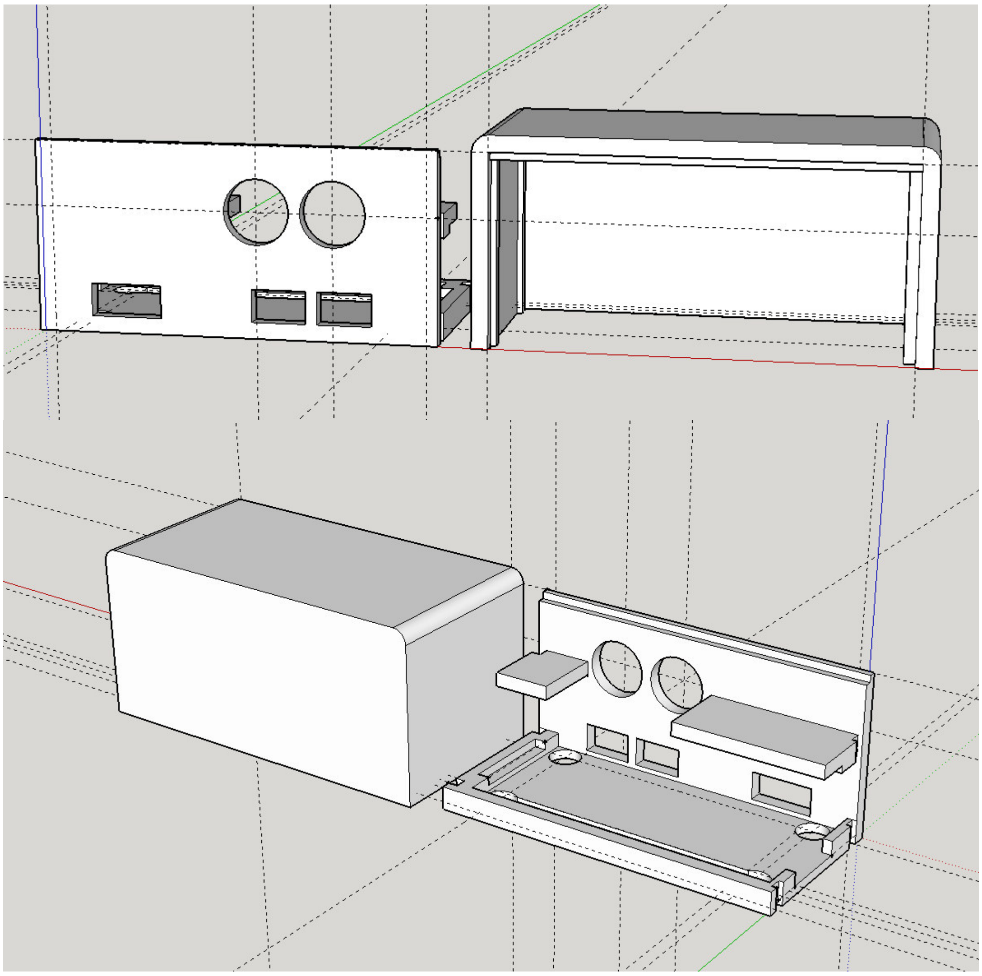


Figure 42: 3D model of separate housing for sound module logics.

To make handling of the two speakers easier and prevent the volume to be adjusted manually with the volume knob, an optional cover for the speakers was designed. A prototype has been 3D printed for handling tests on location (see Figure 43).

Figure 43: Prototype of sound module in combined housing for the Logitech Z150 speakers.

Table 3 shows the hardware component list for the current sound module prototype.

Table 3: GREAT Sound Module hardware components list

1	Raspberry Pi Zero W board
1	IQaudIO PiZero DAC
1	Micro USB Power Supply, 1A
1	microSDHC card, 16GB, Class 10 (industrial)
1	Logitech Z150 Speaker Pair

4 Scent Module

4.1 Basic Considerations

Existing scent dispensers mainly use either of three principles: spraying, ultrasonic vaporizing, or heat vaporizing.
Sprayers typically use fragrences either in cans under presserure or bottles with pump mechanics. The advantage of the spraying technique is that the fragrence remains sealed when the scent dispenser is not in use. A possible disadvantage of the spraying dispensers is that they produce an audible noise when they are actuated.
Ultrasonic vaporizing works by nebulizing fragrences using ultrasonic waves. One advantage of them is that they are nearly silent in operation. However, due to their working principle, they emit ultrasonic noise, which in the context of GREAT is a major downside, as ultrasound is also used as a stimulus. Furthermore, the fragrence is not sealed while not in use, meaning it will vaporize over time, even without actuation.
Heat based dispensers work by heating the fragrence and therefore leading to vaporization of the fragrence. One advantage is their nearly silent operation, however, one major downside of this technique is that by applying heat, the fragrence molecules are modified. Fragrences are not sealed with these models, therefore they might be vaprized over time, even without actuation.

Due to the major downside of the ultrasonic- and heat-vaporizer based models (fragrences not sealed, therefore uncontrolled vaporization), the spraying technology is used for GREAT. While some models already exist on the market, none of them are made to contain multiple fragrences that can be triggered individually and coupled to an automation system - at least not in the envisioned price range of up to 150 Euros. This required us to develop a customized prototype.

4.2 Mechanical Design

The first real prototype was built around a micro metal gear motor from the company Pololu (see Figure 44). The no-load speed at six volts is 30.000 rpm. Since we are using a USB based power shared with a microcontroller, the supplied voltage only amounts to 5 volts instead of the nominal 6V, reducing the max. rpm.

Figure 44: Pololu micro metal gear motor with integrated transmission

The micro metal gear motors come with an integrated gear featuring a transmission ratio of 30:1. Motors with a higher transmission ratios (we tested 50:1, 75:1 and 150:1) are slower

and therefore spread the scents by a pump-action from the bottles in a less favorable way (slower pump speed leads to bigger drops and thus worse distribution in the air). On the other side, lower than the 30:1 transmission ratios cannot produce the necessary force to spray the liquid at all.
To allow for a more compact construction, we mounted a small gear at the end of the drive shaft that attaches to bigger gear. This adds another transmission ratio of 3:13 – resulting in a total ratio of 130:1. See Figure 45 for how the motor is connected to the main gear of the pump mechanics.

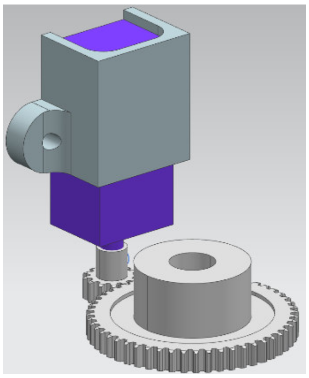


Figure 45: Motor to gear mechanics

The rotational movement is translated into a linear movement by using an eccentric, which is mounted in the center of the final gear. The stroke (see Figure 46) is 2 mm. A linear guide and a fitting carriage ensure a movement along the inserted bottle. This prevents parts from interlocking or getting stuck.

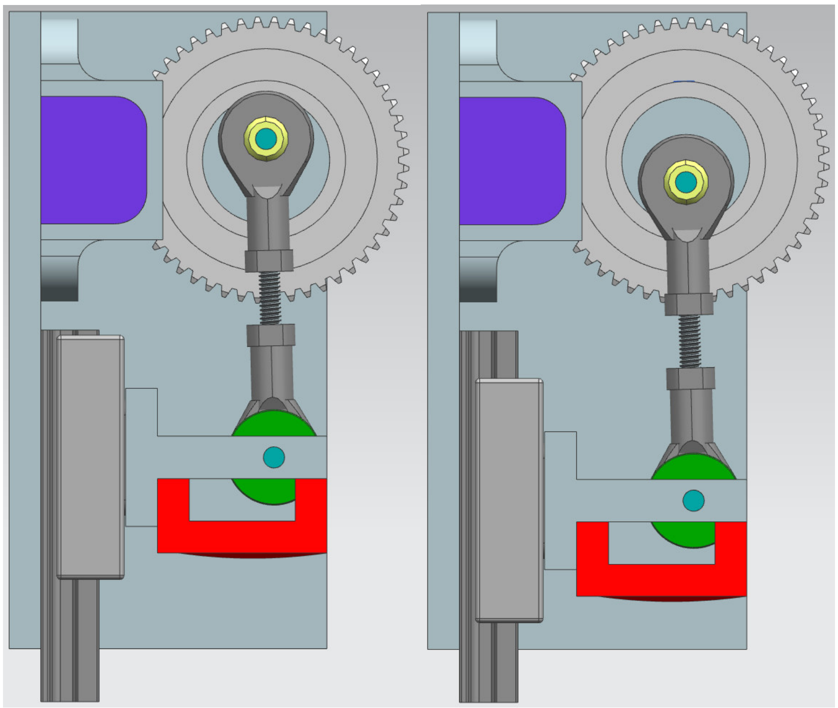


Figure 46: Pump mechanics

This driving part is fixed inside an aluminium box, which also holds one bottle. For each scent, one such box is required. The first one also functions as a mount for the micro controller. Each consecutive box is attached to its predecessor. In the first function test phase, we use two scents. Figure 47 shows the dual scent setup.

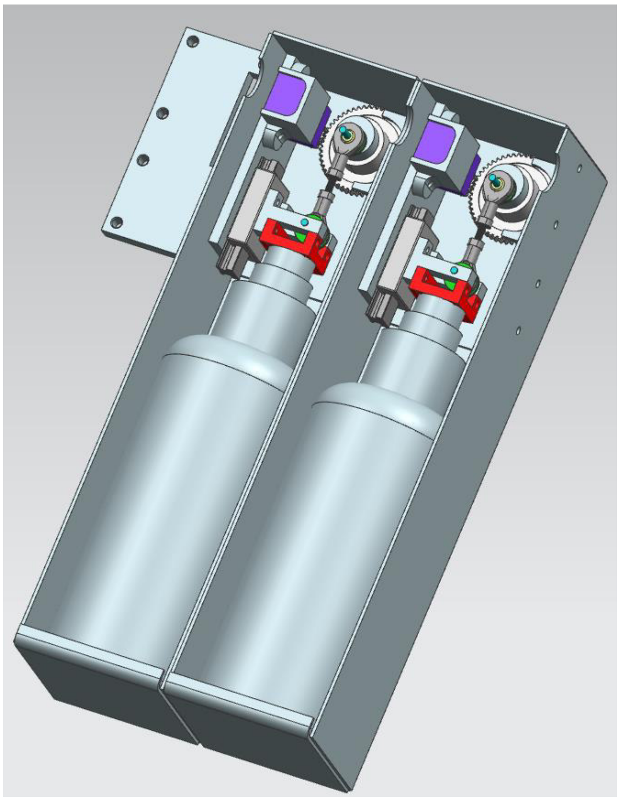


Figure 47: Complete mechanical assembly of the scent dispenser

4.3 Casing

The cover is built out of 2 mm thick Plexiglas, which is processed with a laser cutter. For ease of accessibility, we chose a design, which relies purely on friction. In case of maintenance, no screws or glued parts must be removed and any side is accessible very quickly. This is achieved by cutting additional teeth in the height of the thickness of the material at the border of the touching faces. The attached sides interlock and create an appealing edge. It contains holes for the plug of the power supply, the micro SD-card, exit holes for the sprayed mist and a slot to slide around two screws (see Figure 48). The assembled casing then slides onto the prototype and is held in place by the small ledges at the bottom of the inner casing (aluminum box).

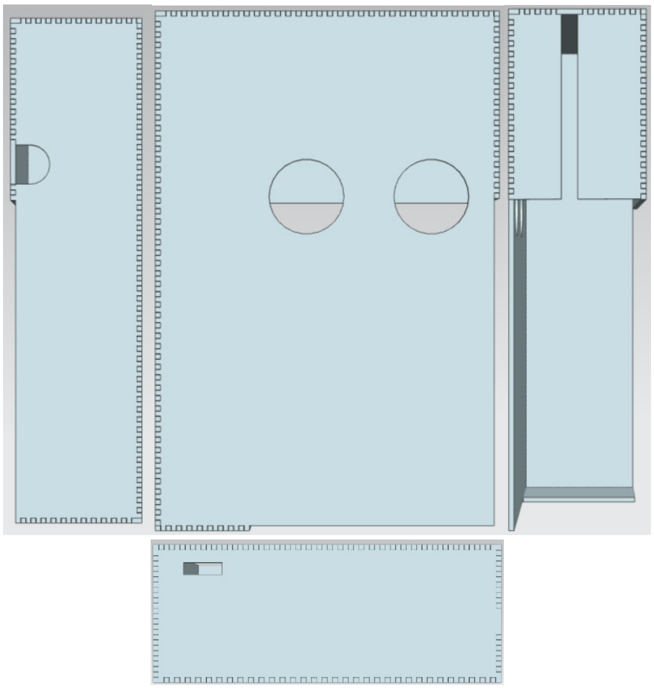


Figure 48: Left hand, front, right hand and top view of the cover of the scent module (from left to right, top to bottom)

Figure 49 depicts the final assembly for the scent module prototypes for the functional tests, showing the bottles inside the respective outlets and the ledge that overlaps with the casing (both center image), as well as the holes for the screws around which the casing must slide (right image).

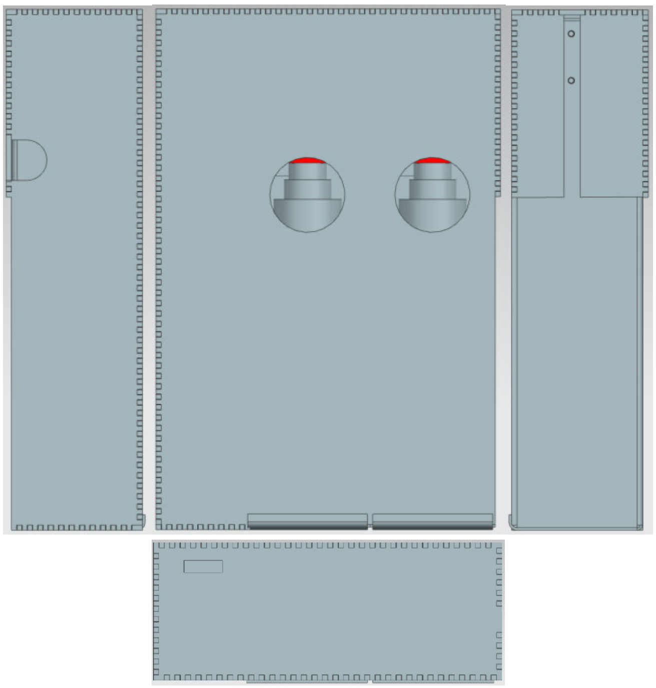


Figure 49: Model of completely assembled scent module prototype.

For the prototypes for the field tests, the casing is optimized to be 3D printed, thus reducing to amount of work required to assemble the whole module. Due to early feedback in functional tests, some changes were made to the case and positioning of the elements too. The controller-electronics will now be placed at the bottom. In this way, the cable of the power supply will leave the case at the bottom edge, and allows the case to be opened without detaching it from the power supply. Also, wholes for wall mounting have been incorporated into the bottom of the case. Figure 50 shows the redesigned 3D models.

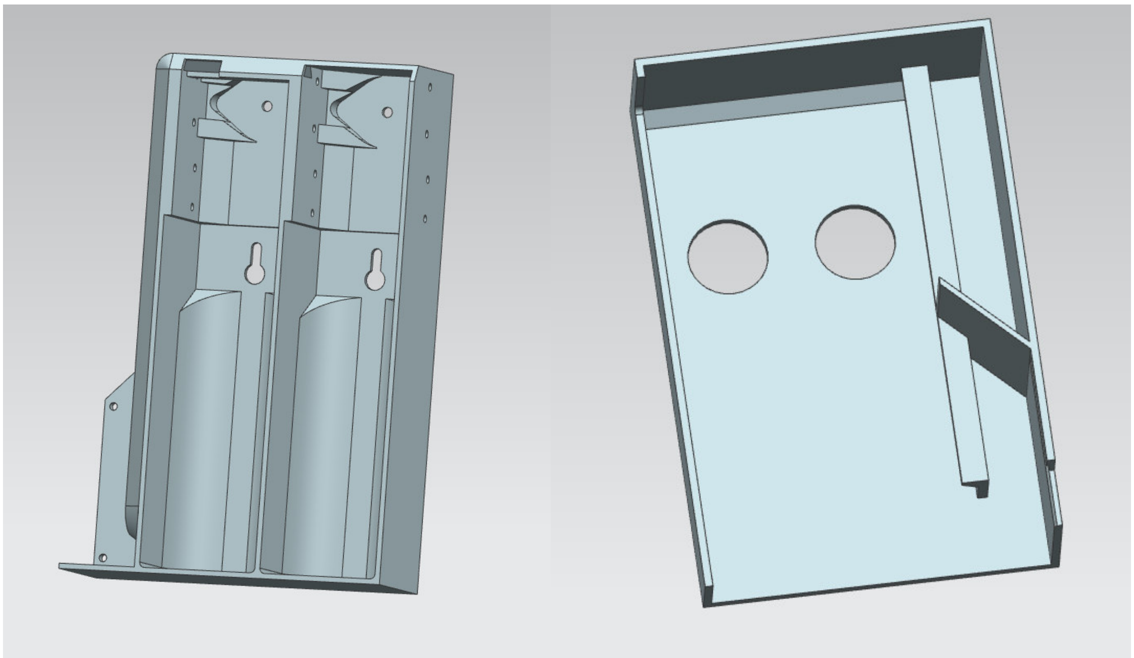


Figure 50: Redesigned housing of the scent module optimized for 3D printing.

4.4 Electronic Design

The scent module is powered by a USB power supply rated at 5V/1A. The main electronic components of the scent module are a controller board, a motor driver unit for the motors and an analog digital converter (ADC) for system feedback. The actuators of the scent module are controlled by a Raspberry PI Zero W board (see Figure 51), that allows for connection to a building automation system over WLAN and handles the logics of dispensing.

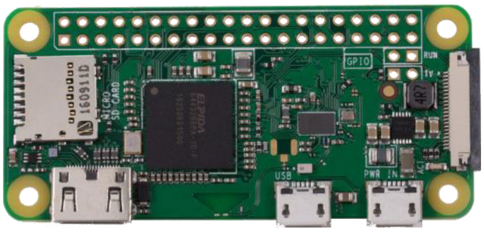


Figure 51: Raspberry Pi Zero W board computer

The motors of the scent module are connected to the Raspberry Pi Zero board via an Adafruit DRV8833 motor driver board that features current limiting (both, for protecting the power supply against overload in case the motor is locked, and against injuries) as well as reverse voltage protection for the controller board. One DRV8833 board allows for the connection of up to two motors (see Figure 52). The DRV8833 board is controlled over digital outputs of the GPIO header of the Raspberry board, and provides fault input via a digital input.

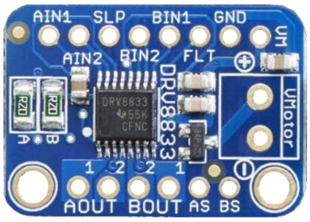


Figure 52: Adafruit DRV8833 motor driver breakout board.

An Adafruit ADS1015 ADC module (featuring 12-bit resolution) is used to measure the current flowing to the motors via a shunt resistor (see Figure 53). The ADC module is connected via an I2C interface to the main controller board.

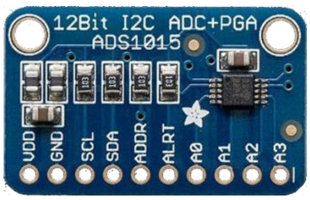


Figure 53: Adafruit 12bit ADC converter ADS1015 breakout board

By measuring the current flowing to the motors the software can detect peaks and values, which relate to the inverse current position of the pump spray. This allows for automatic turn off at the upper position, which allows for easy removal and insertion of scent bottles. Also, the exact number of actuations of the pump spray can be detected in this way (see Figure 54 for typical current flow of the prototype loaded with bottles and without bottles).

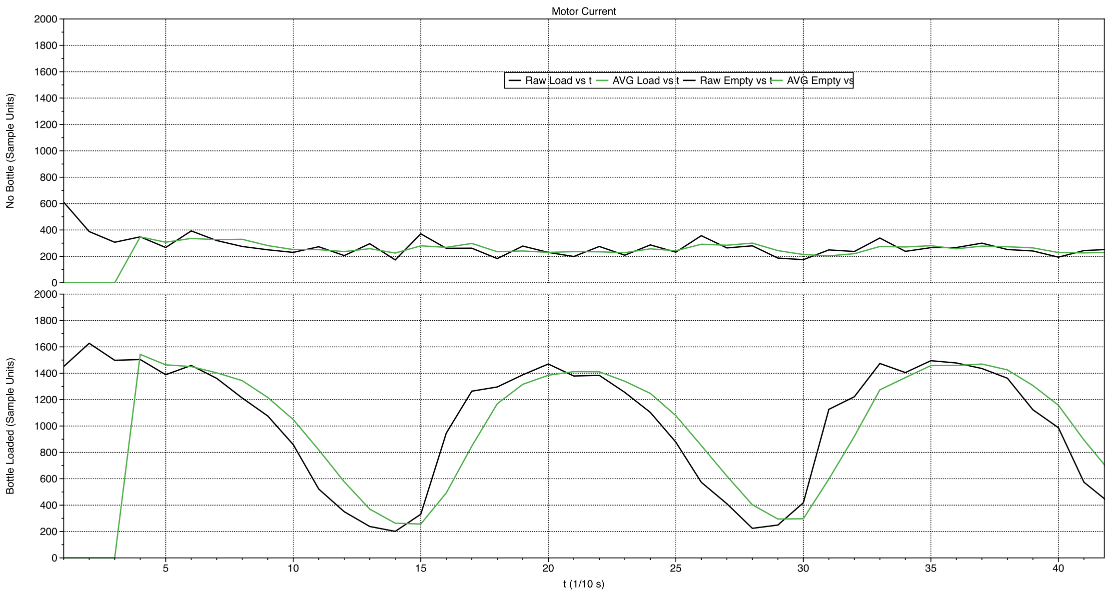


Figure 54: Current flow to motor during pump cycles with no bottle inserted (top), and bottle inserted bottom) as raw signal and smoothed signal.

Figure 55 shows the detailed wiring of the DRV8833 and ADS1015 modules to the Raspberry board.

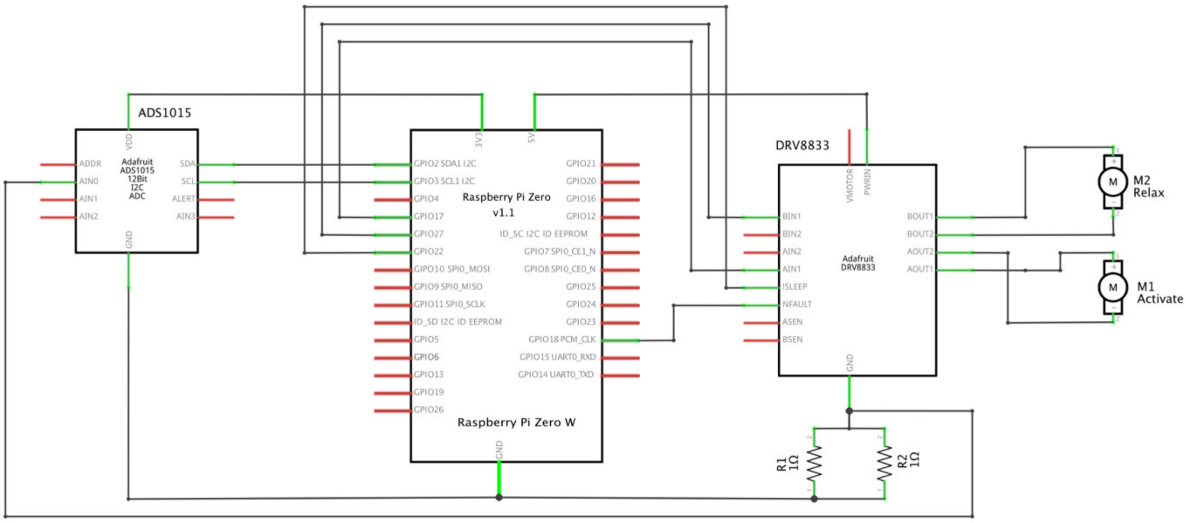


Figure 55: Schematics for the electrical components of the scent module.

While the first prototypes built for functional testing were wired manually, a printed circuit board (PCB) has been designed to make the assembly easier for the field test prototypes. Figure 56 shows the circuit board layout, providing headers to directly plug the individual boards together.

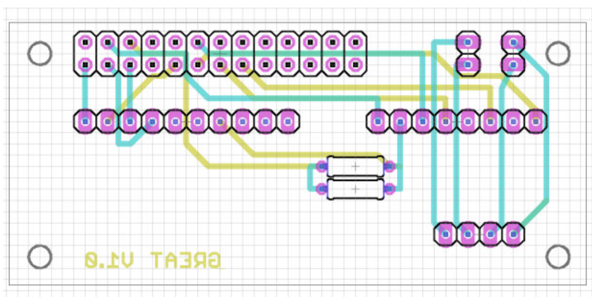


Figure 56: Printed circuit board design for the scent module electronics.

Table 4 shows the hardware component list for the electrical parts of the scent module.

Table 4: GREAT Scent Module hardware component list

1	Raspberry Pi Zero W board
1	Adafruit DRV8833 motor driver breakout board
1	Adafruit ADS1015 ADC breaktout board
1	Micro USB Power Supply, 1A

1	microSDHC card, 16GB, Class 10 (industrial)
2	Resistors 1Ohm ¼ Watt
2	Pololu Micro Metal Gear Motor 6V 30:1

4.5 Functional Tests

To find out about right amount of scent dispensing, we performed tests with the prototype using an iAQ-core sensor for volatile organic components (VOC) measurements. The tests were performed in a closed room without other VOC sources. As a test substance, we used the Primavera Harmony scent. The room temperature was held constant at 22 degrees during the test.

The scent module was mounted in the middle of the room at a height of 2.25 m. The sensor was placed in 2.5 m distance at a height of 0.8 m (desk height). The scent module was programmed to dispense scent in 10 minute intervals, where one dispense action involves a double pump. The first interval started at 0:15 to 02:05 and a second interval started from 7:45 to 8:45). Figure 57: VOC levels over time, with an actuation triggered every ten minutes starting at 00:15, and at 7:45.5 to 8:45). Figure 57 shows the VOC level over time during a weekend, where no persons were present. It is clearly recognizable how the VOC level builds up with every dispensing action in a 10-minute interval. Once dispensing is stopped, the VOC level drops like a typical cool down process in nature (according to an e-function). It can also be observed, that the amount of scent reaching the sensor is dependent on air circulation within the room. Typical delay times between scent dispensing and the sensor reporting an increase, for our test setup varied between 1 min and 5 minutes for this kind of scent (see Figure 58 for a detailed picture).

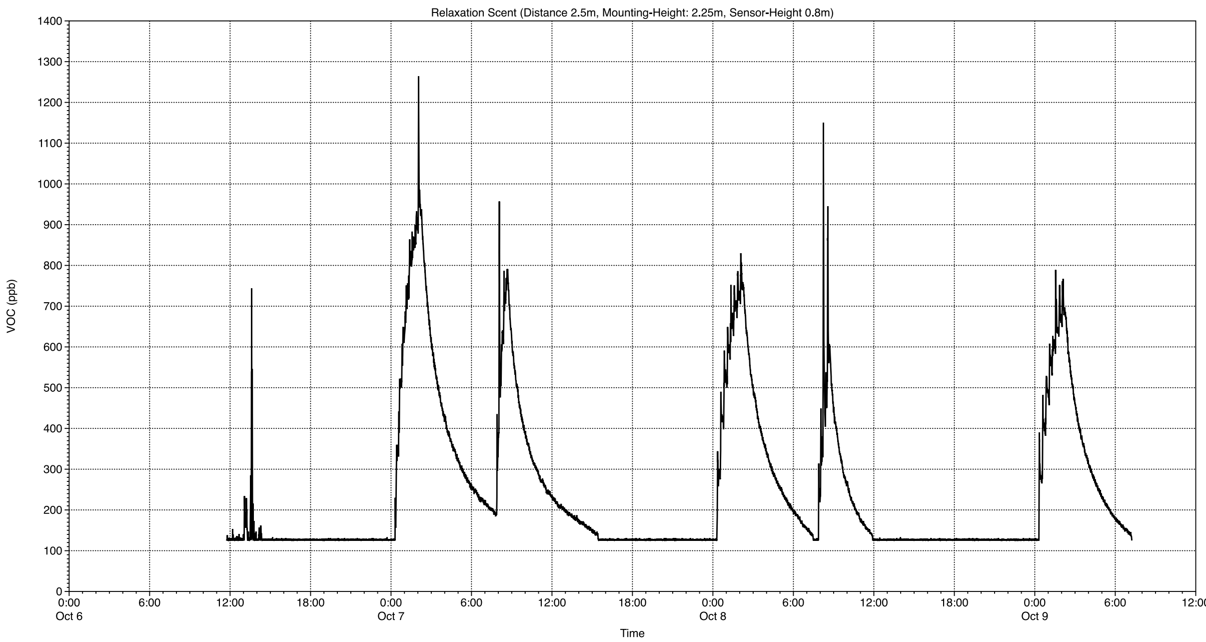


Figure 57: VOC levels over time, with an actuation triggered every ten minutes starting at 00:15, and at 7:45.

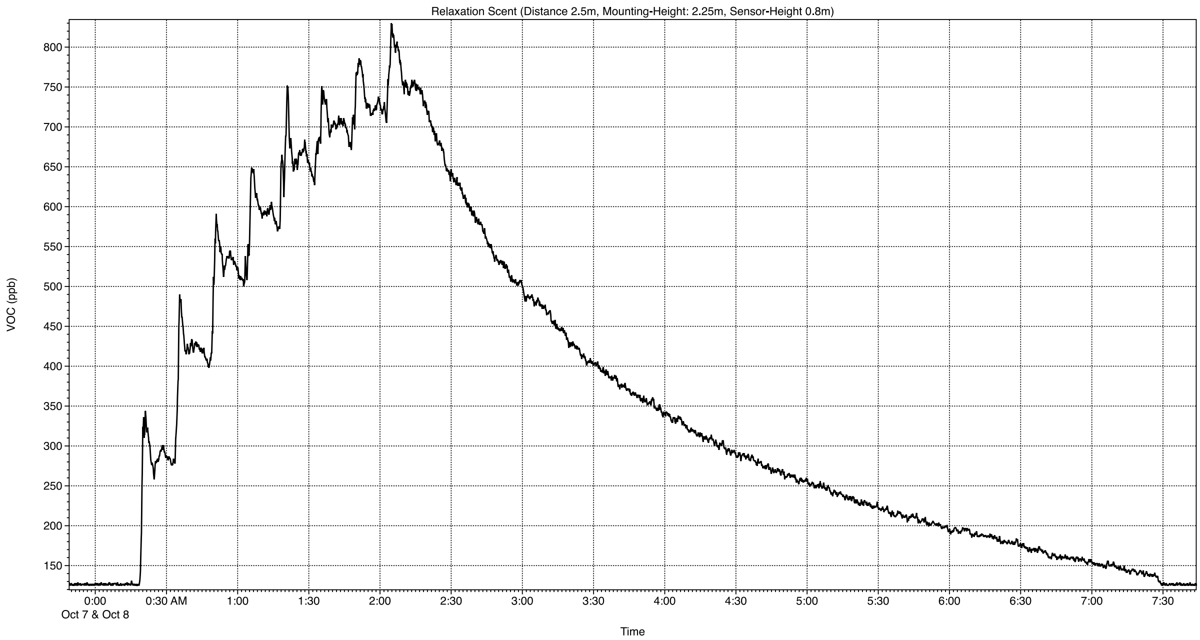


Figure 58: VOC level builds up with every dispense. A delay between 1-5 minutes can be observed.

The actual VOC concentration in µg/ m³ is depending on the kind of scent. According to literature, 300 ppb of VOC measured at 1020 mbar air pressure and 22 degree Celsius are equivalent to the values given in Table 5.

Table 5: Concentration levels equivalent to 300 ppb depending on scent.

Concentration (µg/m³)	*Scent*
2446	Lavender oil (196,29 g/mol)
1922	Rose oil, Citral (154,24 g/mol)
1697	Lemon (136,24 g/mol)
575	Ethanol (575 g/mol)

While the threshold of perception for orange oil based scent is around 1-6 µg/m³ according to Ohloff, 1990 and AGÖF, 2007. The typical concentrations produced by room scent dispensers are in the range of 3000-5000 µg/m³ (Heitmann, 2008). TVOC concentrations between 3000 to 10000 µg/m³ are considered to be critical, and values over 10000 µg/m³ are considered inacceptable by the German Umweltbundesamt (2007). However, these values mostly relate to solvents and might be overly cautious for aroma therapy purposes.

Considering this information, our proposed dispensing of two times for activation within 20 minutes would reach the typical levels of 400-500 ppb, which according to these recommendations would be OK. For relaxing sessions, we would however suggest three dispense actions, one every 20 minutes, over the course of an hour to also to stay on the safe side, in contrast to the originally proposed dispense action every 10 minutes over the course of 60 minutes.

For the field tests, however, we will have to do on location measurements to tune the system to the local environment, as air circulation within the room, as well as other already existing scents and VOC might have a strong impact on the total measured VOC levels.

5 Sensor Technology

5.1 Sensors for acquiring activation and relaxation status

The sensors used to detect changes in the activation and relaxation level of the group follow two approaches. Ambient PIR (passive infrared) sensors measure group activity based on frequency of motion detection. As soon as at least one person is in the room, the system uses the PIR sensors to continuously determine the relative activity level in the room (estimated number of entries/exits per time unit, estimated number of persons, total movement per area and person). The PIR data cannot be assigned to any person.

Body worn sensors are in use for caregivers to measure activity level and stress level. Wearables and smart textile for the patients are not in use due to the vulnerability of the target group and expected difficulties with acceptance and adherence.

5.1.1 PIR Sensor

The standard use case for PIR sensors is triggering lighting on basis of detected movement or presence. Part of further investigation is the detection of inactivity. Can the presence of inactive presence be recognized by history knowledge about the number of persons entered the room? For GREAT the main aspect is monitoring of activity and detection of group activity levels.

For the activation of lighting the sensor is typically triggered once by motion or presence and switches the light. For a period of 60-90 seconds or more the light is activated and the sensor falls into a sleep mode to conserve energy. After that sleep period the sensor starts to detect activity again. If no activity is detected, the light is switched off otherwise the light stays on and another sleep period starts.

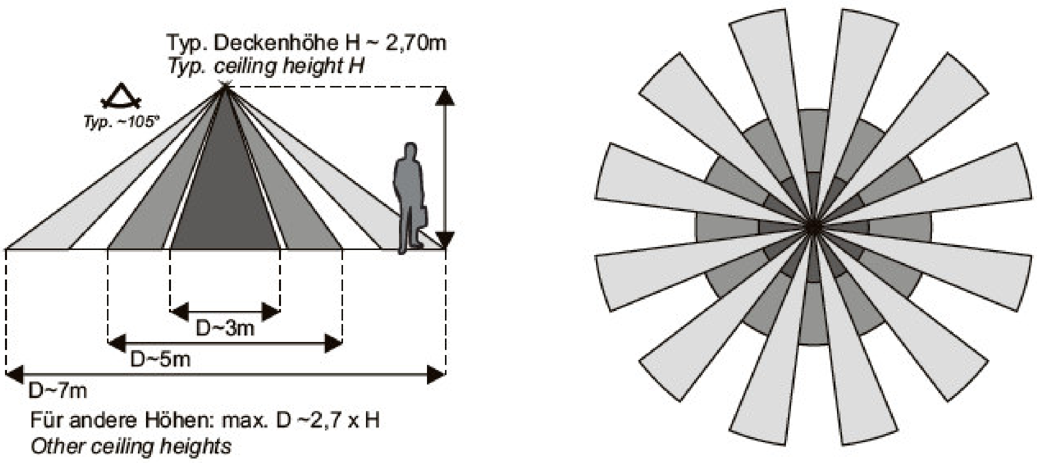


Figure 59: Detection range

The requirement for GREAT is to continuously detect activity. Therefore, the sleep period has to be as short as possible. To support convenient and modular installation the second requirement is wireless technology. Since there is a conflict between a wireless and energy-saving architecture and high frequency detection the chosen product has to be modified. The minimum sleep period was reduced to about 1 second. An additional modification is made due to the fact, that the sensor is placed on top of the ceiling and not as concealed-installation Figure 59. If the human heat source moves through the individual zones, different charge differences are generated on the associated sensor elements and a movement can be detected over a large. The main issue would be to recognize not only movements and classify a single person's activities as shown in (Nef et al. 2015; Luo et al. 2017), but also how group activities can be classified and what this means related to a stressful or too calm situation. The sensor uses an optical shell combined with a magnetic cap to provide easy access in case of battery change without the necessity to completely removing the sensor. For GREAT the Thermokon “EasySens” SR-MDS BAT will be used (for technical specifications see Table 6, picture see Figure 60.

Table 6: Technical specification for Thermokon SR-MDS BAT

Vendor	Thermokon Sensortechnik GmbH (Germany)
Series	EasySense
Type	SR-MDS BAT
Retail price	250,00 EUR
Technical design	Wireless
Wireless technology	EnOcean ISO/IEC 14543-3-10
Radio frequency	868,3 MHz
Functions	Motion detection and brightness measurement
Motion detection	Passive infrared
Detection area	360°; 105° conical (ceiling installation)
Detection radius (2,5 m room height)	3,25 m
Power source	3 x Battery 3,6V 1/2 AA LS14250
Brightness (Accuracy)	0-510 Lux (+/- 30 Lux)
Sleep time interval (modified)	1s – 1000s

Figure 60: Thermokon SR-MDS BAT with extra light 3D printed cover

5.1.2 Body worn sensor

Changes in activity and stress or relaxation level can be measured by body worn sensors, which measure corresponding physiological parameters like heart rate, skin conductance or motion patterns via accelerometers. The Everion sensor from the company Biovotion (Zurich, Switzerland) makes use of various sensing techniques which can all be applied on the upper arm. There are several optical channels based on different colours to detect changes in subcutaneous tissue and a galvanic skin response sensor (GSR). Based on this raw data the human understandable vital parameters are calculated. The vitals available are listed in Table 7. The most interesting and most often used parameter for stress recognition is the heart rate variability (HRV). It is calculated based on the beat to beat (R-R interval) as illustrated in Figure 63. The HRV of a well-conditioned heart is typically large at rest. It might decrease in case of activity or interesting for us in case of mental stress. Biovotion applies to root mean squared of successive differences (RMSSD) to calculate the HRV. For our algorithm to recognize stress phases as shown in Figure 63, we apply three functions on the R-R intervals (according to Ulrich Reimer et al., 2017):

- SDNN: standard deviation of RR intervals (i.e., intervals between two heart beats)
- RMSSD: root mean square difference of successive RR intervals in the time frame
- PNN50: percentage of pairs of adjacent RR intervals differing by more than 50 ms.

Figure 61: Biovotion Everion upper arm sensor

Figure 62: Enverion back with light and galvanic skin sensors

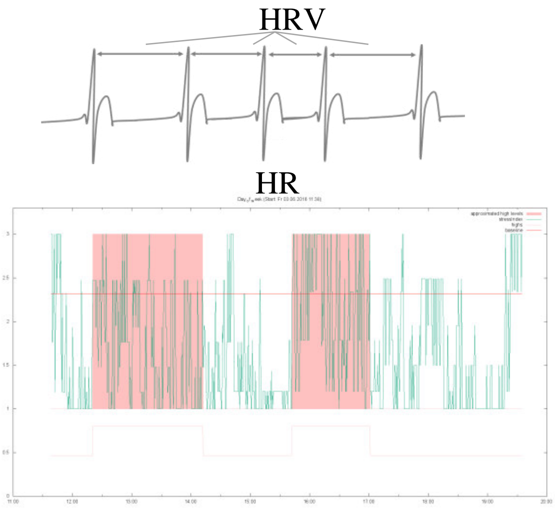


Figure 63: HRV signal and marked high stress segments

Therefore, we need the R-R values in milliseconds which are provided every second (1Hz). Together with the main vitals, a quality value in the range of 0-100 is provided. Values with a quality below 50 are ignored.

The algorithm applied in detail to derive the stress segments with the result shown in Figure 63 is described in detail in (Ulrich Reimer et al. 2017).

Another interesting testing parameter for our application might be the GSR, also referred to as Electrodermal Activity (EDA), which measures changes when starting to sweat. This is commonly used as a sensitive measure for emotional arousal. The GSR provided every second is expressed in a value between 0 – 65535 and has a conversion factor of 1/3000.

The advantage of the Enverion in comparison to other sensors is its approval in Europe as a medical device for heart rate (HR) and blood oxygenation or oxygen saturation (SpO2) and its ISO certifications (ISO 1345). An approval by the FDA in the USA is currently ongoing. Also, the higher level of acceptance is an advantage which has been shown in our tests at the sleep laboratory where the devise has been applied by over 40 healthy test persons and over 30 unhealthy persons in parallel to ECG with electrodes attached and wrist worn devices (Reimer et al. 2017). The sensor is lightweight and convenient to wear, can store data locally, transmit data in real-time or whenever in range of a gateway and can be recharged easily by placing the sensor onto a conductive charging cradle. The comfortable wearing is supported by an elastic textile band available in different sizes as shown in Figure 64.

Figure 64: Different sizes of bands for an optimal fit

Table 7: Technical specification for Biovotion Everion

Vendor	Biovotion AG (Switzerland)
Type	Everion
Price (project)	550,00 EUR
Technical design	Wireless with rechargeable battery
Wireless technology	Bluetooth 4.0 + LE (IEEE 802.15.1)
Transmission range	<10 m
Radio frequency	2,4 GHz
Parameters	Heart rate Blood oxygenation Skin temperature Skin blood perfusion Steps / Motion
Experimental parameters (project)	Respiratory rate Heart rate variability Energy expenditure Blood pulse wave Skin conductance
Data modes	Vital sign parameters, raw data, mixed mode
Battery life	24 h
Power source	Embedded Li-Ion battery rechargeable

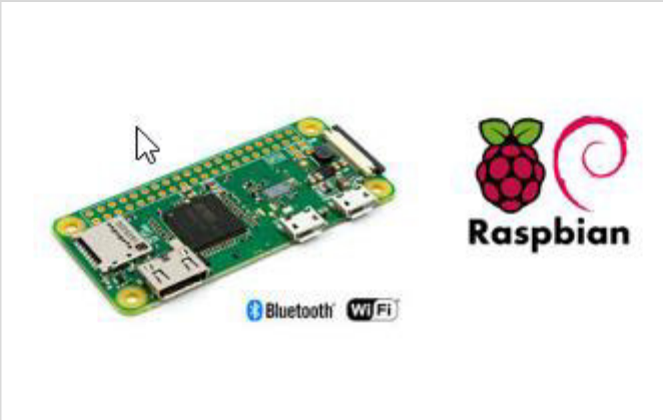
The sensor can transmit pre-calculated vital sign data or raw data from every parameter channel in real-time or buffer it to the internal memory. The memory can hold several days of vital sign data or 4 hours or raw data. The sampling rate of raw data at 53 Hz with 12 different channels causes a heavy data volume which leads to asynchronous data transmission over time (transmission is slower than recording of raw data).

In GREAT the vital sign mode is the preferred mode since the basic vital parameters are calculated in real-time for detection of changes in activation/relaxation and physical activity levels. For receiving data a gateway has to be installed. Different variations are currently evaluated and considered for use. The preferred gateway is a Raspberry Pi 3 board controller which is also in use as the main controller of the GREAT system. Alternatives can be smartphones with an Android operating system or a Raspberry Pi Zero, which is the cheapest of all variations. The vendor currently only supports Windows and Android operating systems. Those variations rely on more expensive hardware like Stick-PCs based on Intel architecture, which is in conflict with a cheap end user price. To provide maximum compatibility and avoid problems with different Bluetooth stacks of different hardware components the vendor developed his own BT-Dongle. This dongle is also expensive (120 CHF). Different alternatives including advantages and disadvantages as well as the price tag are listed below (Figure 65).

For the functional tests, we start with the PC-Stick version and transfer the collected vitals every evening to our Cloud Server where also the logs from all devices are stored.

For the field tests, we head for the cheaper variant with a Raspberry Pi 3, Android and the fully functionally Android App. This porting activities are ongoing. The working PC-Stick solution will be kept as a fallback for the field tests.

Variation	Pro/Cons	Price (CHF)
Intel Stick-PC with Windows 10 and BT-Stick		
 	Pro: Use of existing software Cons: Expensive Stability issues	250
Raspberry Pi 3 with Windows		

	Pro: Cheap Cons: Porting of software	170
Raspberry Pi Zero with onboard BT		
	Pro: Cheap Board in use in other modules Cons: Porting of software	30
Raspberry Pi 3 with Android		
	Pro: Cheap Software under development by vendor Cons: Stability issues	60
Raspberry Pi 3 with Wine Emulation		

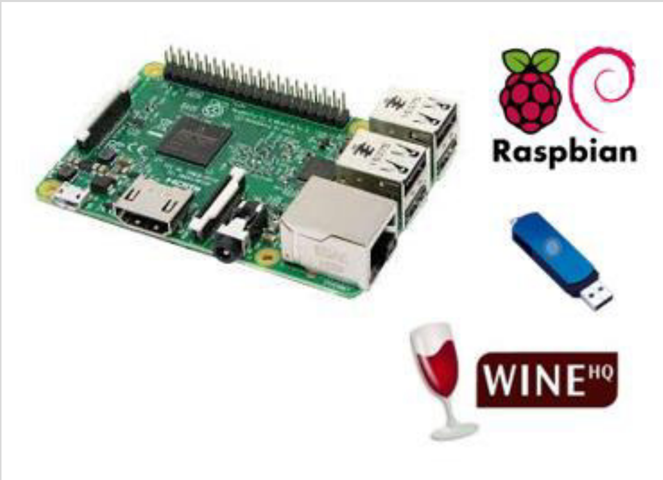
	Pro: Use of existing software Cons: Dongle expensive Licensing cost	150

Figure 65: Variations of gateways for data retrieval

6 Controlling

6.1 Hardware

The main controller is based on a Raspberry PI 3 board-computer (Figure 66). It features a Broadcom BCM2837 system on a chip with four ARM Cortex-A53 cores clocked at 1.2 GHz. It includes 1 GB of LPDDR2 RAM and features a 10/100 Ethernet port, a 2.4 GHz 802.11n wireless module and a Bluetooth 4.1 LE module. For extension, it offers 4 USB2 ports and a 40-pin GPIO header (e.g. providing support for I2C, I2S, SPI, UART interfaces).

To integrate EnOcean components, a Raspberry Pi EnOcean module based on the TCM310 EnOcean transceiver module is connected to the built in UART via the GPIO header of the Raspberry. For better signal performance of the EnOcean modules, an external 868 MHz antenna is connected to the EnOcean module. Table 8 lists the hardware components required for the GREAT controller.

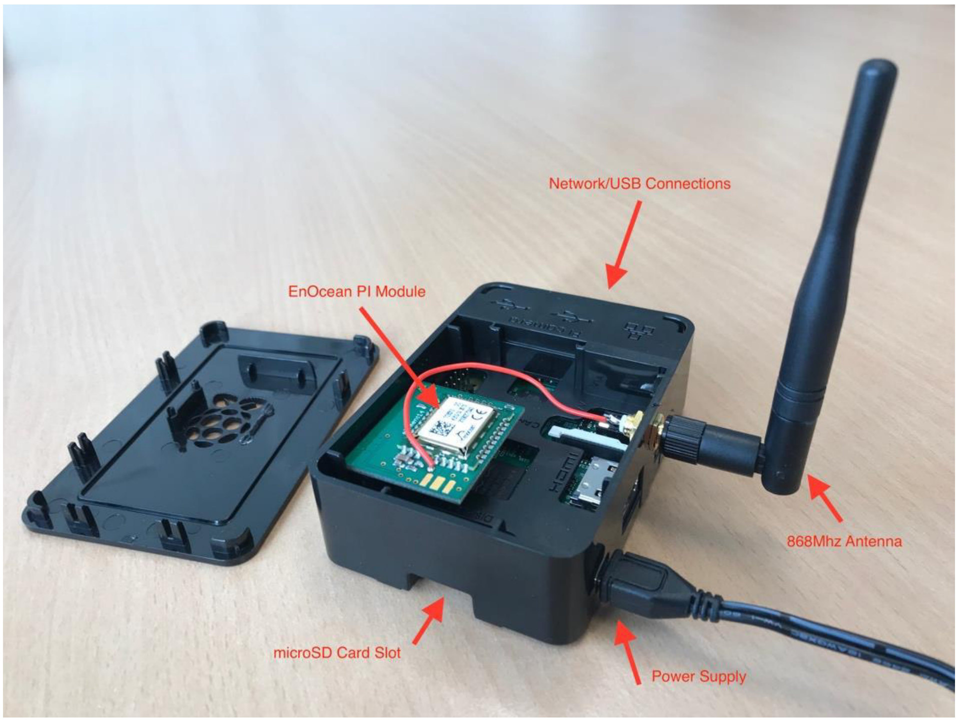


Figure 66: Controller setup based on Raspberry PI 3 and EnOcean PI 868 MHz module

Table 8: GREAT Controller hardware component list

1	Raspberry Pi 3 board
1	Casing for Raspberry Pi 3

1	Micro USB Power Supply, 2.5A
1	microSDHC card, 16GB, Class 10 (industrial)
1	EnOcean PI 868 module for Raspberry
1	868MHz Antenna H-Tronic 1618110
1	SMA-Connector Socket

The reasons for choosing the Raspberry PI 3 board as basis for the controller instead of other single board computers (e.g. like the Beagle Bone boards) were price, strong community support including a wide range of extensions, and most importantly built-in wireless support.

For a documentation of the software architecture and features see Deliverable 2.2.

7 References

Light:

[1] Lighting concept based on literature search see D1.1

Scent and Sound:

[2] AGÖF (2013). Orientierungswerte für flüchtige organische Verbindungen in der Raumluft (Aktualisierte Fassung November 2013), Online available: 30.11.2017, URL: http://www.agoef.de/orientierungswerte/agoef-voc-orientierungswerte.html

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8 List of figures

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