Ambient Light Guiding System for the Mobility Support of Elderly People

Applicable hardware components

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Preface

This document forms part of the Research Project "Ambient Light Guiding System for the Mobility Support of Elderly People (Guiding Light)" funded by the Ambient Assisted Living Joint Programme (AAL-JP) as project number AAL 2011-4-033. The Guiding Light project will produce the following Deliverables:

D1.1 Medical, psychological, and technological framework

D2.1 Applicable hardware components

D2.2 Applicable software components

D3.1 Solution package description

D3.2 Implementation report

D4.1 Communication strategy

D4.2 Stakeholder management report

D5.1 Field test report

D6.1 Report on market analysis

D6.2 Dissemination plan

D6.3 Final business plan

D7.1 Consortium Agreement

D7.2 Periodic activity and project management report

D7.3 Final report

The Guiding Light project and its objectives are documented at the project website www.guiding-light.labs.fhv.at. More information on Guiding Light and its results can also be obtained from the project consortium:

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1. Lighting Concepts

1.1. Description of the basic room lighting concept

Based on the scientific findings on lighting requirements for elderly people to fulfil visual and biological needs (see Figueiro et al, 2011; Rea et al., 2012; Stripling, 2008; Veitch & Galasiu, 2012) and the survey of market-based lighting solutions respectively concepts including luminaires and additional components (see D1.1), two main lighting components build up the "Guiding Light" lighting concept:

- ambient lighting component: homogeneous diffuse room illumination
- task lighting component: zonal glare-free lighting with high intensities

These two components are controlled separately and thus allow to illuminate the rooms with a multitude of lighting scenarios. The lighting concepts are analysed with respect to autonomous indoor wayfinding and spatio-temporal navigation assistance (see Chang et al., 2010; Chung et al., 2011).

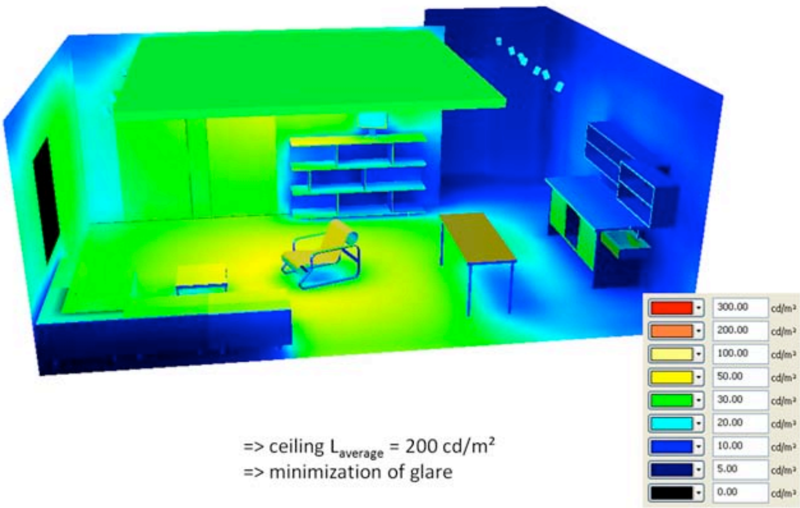


Fig. 1 False color visualization of the ambient light situation

Fig. 1 shows in a false color visualization (colors represent luminance values) the simulation[1] results of an ambient lighting situation. The ambient lighting component was simulated by a diffuse shining "ceiling". This situation could be realized by technical systems shining onto the ceiling in order to utilize it as secondary reflector. The result shows that a homogeneous illumination is achieved mostly within this room, except extraordinary angular spaces. Therefore additional luminaires have to be foreseen for such areas. The result shows also a balanced ratio between horizontal and vertical intensities.

[1] All simulations were carried out with the software tool "Dialux 4.11".

Sufficient vertical intensities are obligatory to achieve physiological light effects. The utilization of the ceiling is necessary in order to minimize glare, i.e. keep maximum luminance onto ceiling, walls, etc. below 1000 cd/m².

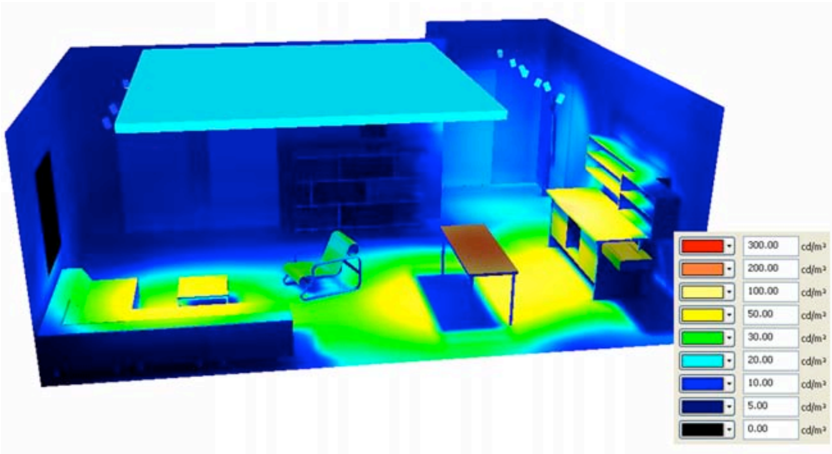


Fig. 2 False color visualization of a zonally task light situation

Fig. 2 shows an example of a zonally task light. The technical realization could be with zonally shining spots[2] additionally (and separately controllable) to the ambient light. The goal of the task light is to establish best (according to the visual needs of elderly persons) illumination values at pre-defined working areas (e.g. desks, kitchen sideboard, reading places, etc.). Illumination values up to 2000lx are needed according to the requirements [1]. The task light guarantees a high visual performance.

Fig 3. depicts a “full lighting scenario” (i.e. all luminaires are switched on):

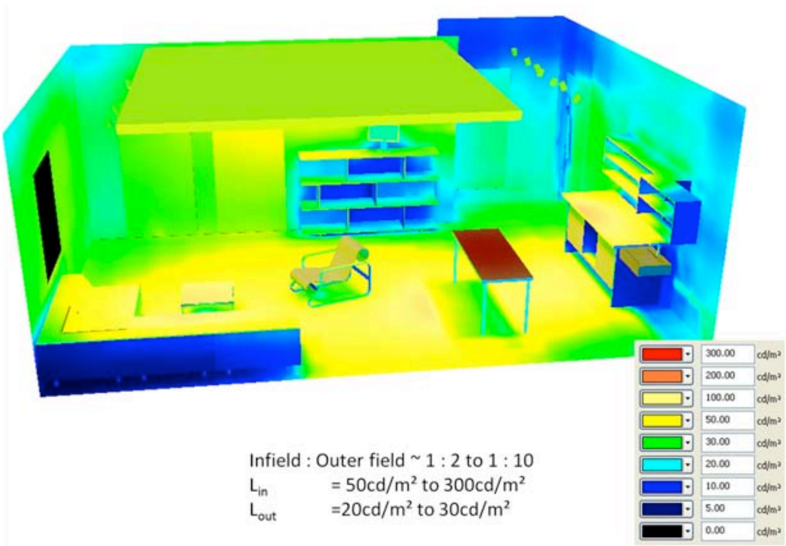
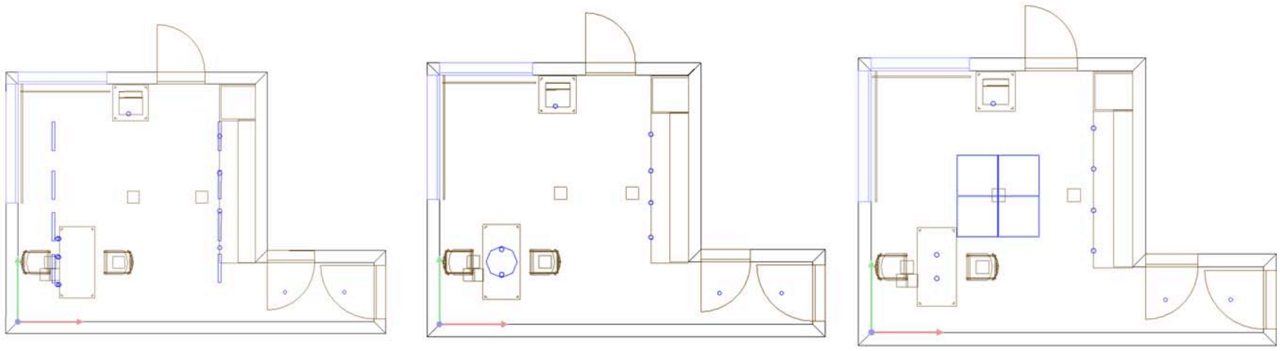


Fig. 3 False color visualization for the situation “all luminaires switched on”

[2] mounted with power busses

1.2. Overview of three different luminaire concepts



Conzept 1: „Ceiling Washer (CW)“ Conzept 2: „Pendelleuchte“ Conzept 3: „Light Fields“

Fig. 4 Overview of concepts which were elaborated in detail

Within several brainstormings and many meetings (internal of the Bartenbach team as well as with the project team and during consortium meetings) many ideas and concepts were discussed. After pre-evaluations the three most promising concepts were chosen for detailed elaboration.

Fig. 4 shows top views of these three concepts within an usual living room of the Guiding Light target group (it is the living room of one test person of the field test apartments in Götzis (AUT). The technical realization of the task light with spots (zonally narrow light intensity distribution) mounted on power busses is similar within all concepts.

Concept 1 "Ceiling washer" comprises a new product development of a suspended luminaire which shines towards the ceiling. These, so called, ceiling washers have to be mounted linear in exact defined distances to walls and ceiling.

Concept 2 "Pendelleuchte" comprises as centrepiece a new product development of a suspended round luminaire. This "Pendelleuchte" consists of two main parts: a direct top-down shining task lighting component and a very powerful ambient lighting component which uniformly illuminates the ceiling. These two parts are separately controllable.

Concept 3 "Light Fields" is the only concept which utilizes only luminaires already available on commercial market (i.e. no new product development). Beside the spots (=task light) the product "Light Field" (from Zumtobel) was used for achieving the ambient room illumination. These “Light Fields” are having a nearly diffuse[3] light intensity distribution.

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[3] i.e. lambertian distribuion

1.3. Concept 1 "Ceiling washer"

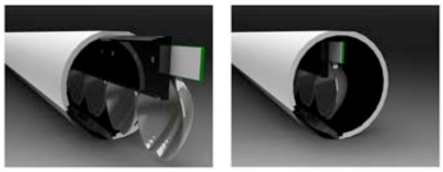


Fig. 5 Technical feasibility study of ceiling washer

Fig. 5 shows a visualization of the technical feasibility study of the new product development "Ceiling washer". This luminaire houses LEDs in order to have tuneable white light colours and a continuously dimming curve. Every single LED is equipped with a complex surface optics which guarantees optimal light intensity distribution. The whole technical parts are mounted inside a tube which has to be suspended with correct distances to walls and ceiling.

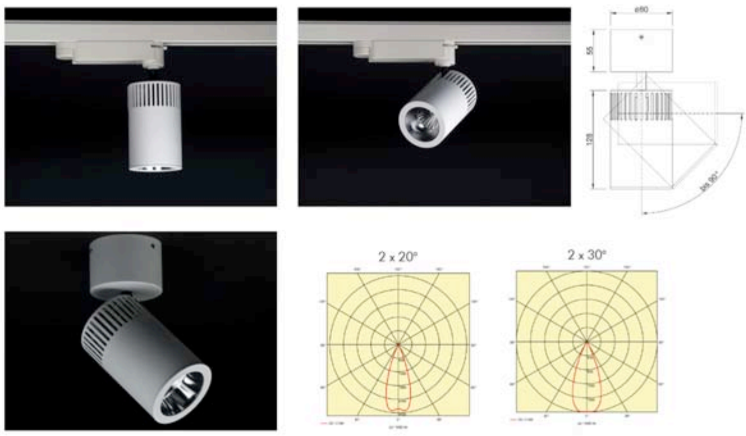


Fig. 6 Spot lights used for zonally task light

Fig. 6 shows photos, dimensions and (narrow) light intensity distributions of LED-based spot lights mounted on power busses. With these luminairies task lighting could be realized. The narrow light distribution is needed to generate zonal illumination.

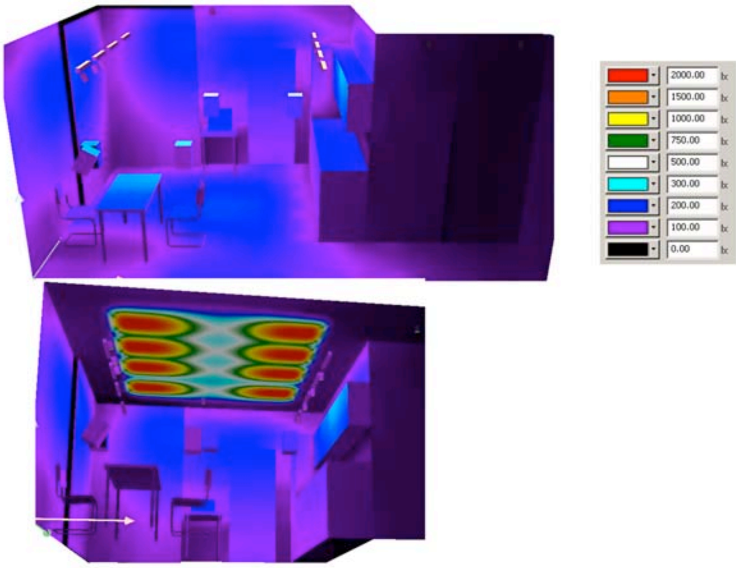


Fig. 7 False color visualization for the situation ambient light with ceiling washer

In Fig. 7 a false color visualization of a simulation of the light distribution is given. The ceiling washers are illuminating the ceiling which acts as a secondary reflector. Although the distribution of light onto the ceiling is not perfectly homogeneous it fulfils the required glare specifications (pre-defined luminance restrictions) very well.

1.4. Concept 2 "Pendelleuchte"

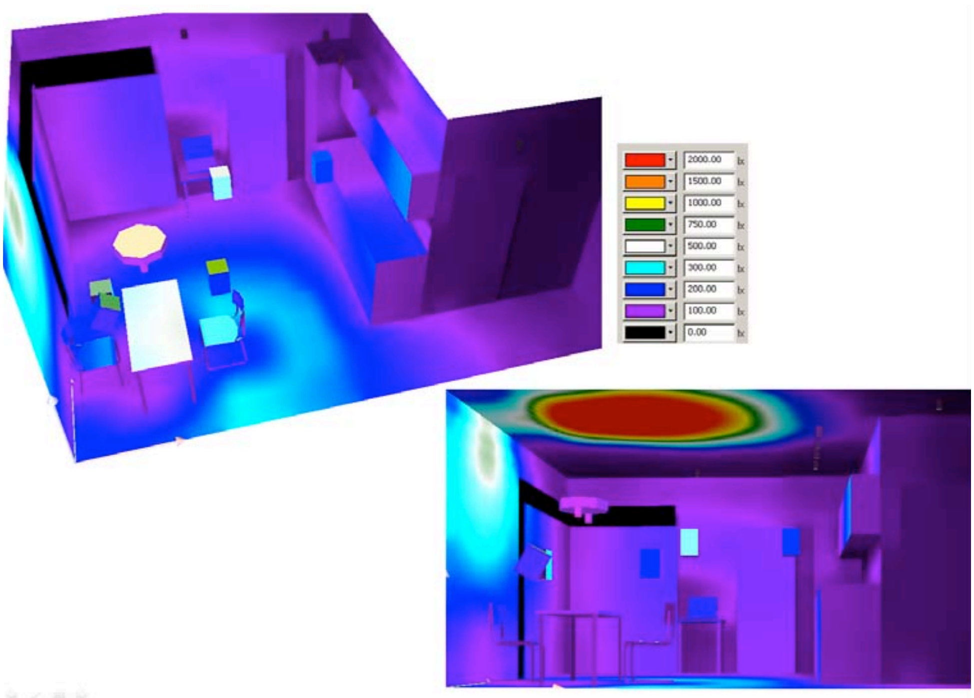


Fig. 8 False color visualization for the situation ambient light with a suspended luminaire

In Fig. 8 a false color visualization of a simulation of the light distribution is given for the second lighting concept. In contrast to concept 1 the ceiling homogeneity is optimized, but the simulation shows that there is still not yet a perfect brightness homogeneity. Within the simulation the light intensity distribution was assumed to be rotational symmetric but special attention could be paid during the technical realization. The "Pendelleuchte" has to be new developed.

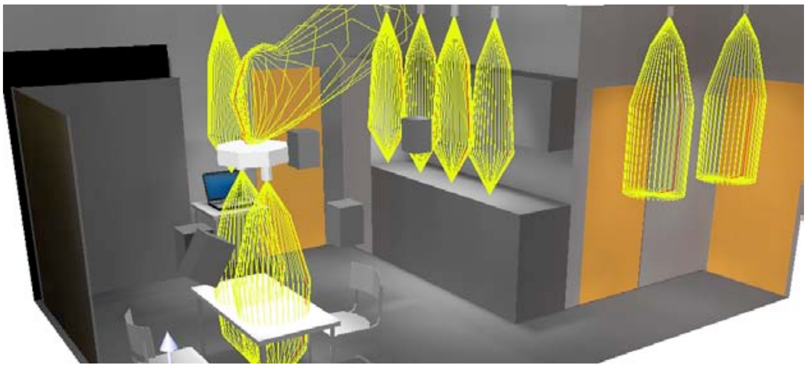


Fig. 9 Schematic visualization of the light intensity distribution of the luminaires

Fig. 9 shows a schematic of the light intensity distributions. The very narrow distributions of the spots lights are clearly observable in order to realize the zonally task lighting. In this figure also the ambient lighting by the aid of the "Pendelleuchte" is illustrated. A broader distribution is optimized in order to shine homogeneous towards the ceiling.

1.5. Concept 3 "Light fields"

This is the only investigated concept which comprises solely commercial available products. Beside the spots used for task lighting a product of Zumtobel with a diffuse light intensity distribution is used for realizing the ambient lighting.
The following figure in an illustration of such a luminaire. The light fields emit nearly diffuse light and are surface-mounted onto the ceiling.

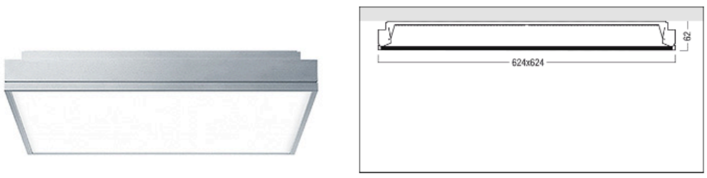


Fig. 10 Illustration of a Zumtobel light field

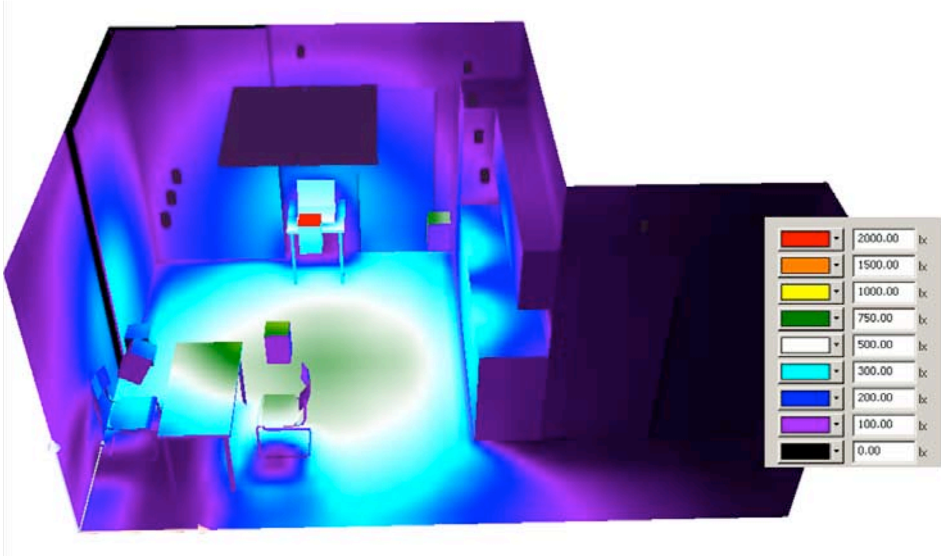


Fig. 11 False color visualization for the situation ambient light with light field

In Fig. 11 a false color visualization of a simulation of the light distribution is given. It shows the lowest homogeneity at floor level of the three concepts. Another strong disadvantage is a "dark" ceiling (because it isn't illuminated). This causes a decline in stable perception and reduces a pleasant room atmosphere. Another result of the simulation was that several light field are needed for a usual living room in order to achieve the required illuminance values. I.e. large areas of the ceiling are covered with these luminaires and are exceeding the luminance value due to the glare requirement ($L_{ceiling/luminaire} < 1000$ cd/m²).

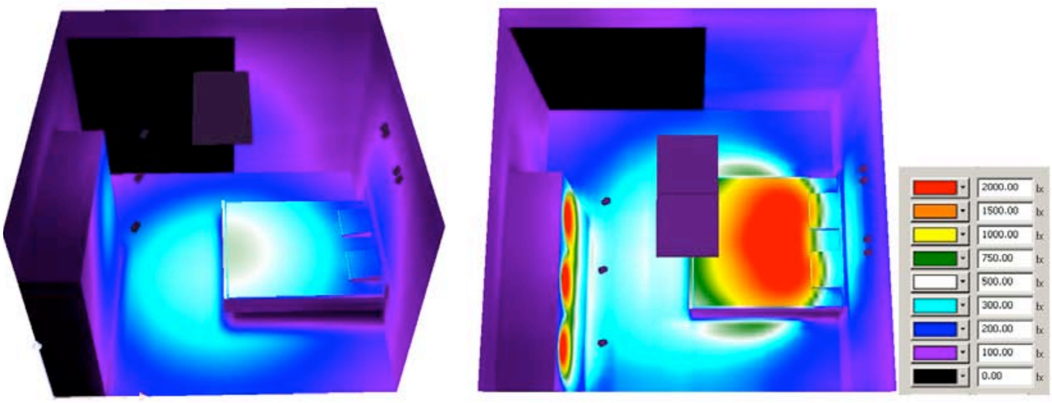


Fig. 12 False color comparision of different lighting situation within the sleeping room with light fields

Fig. 12 shows the simulation results in false color illustration of the sleeping room. It is comprised with light fields and spot lights. On the left side the ambient light situation is given. On the right side the simulation shows additionally task light: Predefined zones (in this case an reading area and the cupboard illumination) feature the required maximum of 2000lx.

At the moment of these conceptual investigations it was foreseen to equip all field test apartments within the sleeping room and the bath room with light fields and / or spot lights (commercial available). This was due to the estimation of overall material costs.

1.6. Comparison of concepts

	Concept 1: „Ceiling Washer“	**Concept 2: „Pendelleuchte“**	**Concept 3: „Light Fields“**
Tunable White for „Ambient light“	**2700K - 4000K** Ceiling Washer TUNABLE WHITE in all rooms!	**2700K - 4000K** Pendelleuchte (in living room) 3000K Light Field (other rooms) TUNABLE WHITE only in living room!	3000K Light Field No TUNABLE WHITE!
Glare	**1000 cd/m²**	**1000 cd/m²** (living room) 1500 cd/m² (other rooms)	1500 cd/m²
Room height			
Planning effort			
Appearance in private home			
Individualization			
Product on market			

Fig. 13 Table with comparison of the different light concepts

Fig. 13 shows the pros and cons of the three concepts. Concept 1 and 2 featuring best lighting performance, especially concept 1 is fulfilling all Guiding Light requirements.

Concept 3 is the only elaborated concept which only comprises commercial available products, but essential requirements are not met: The glare requirement is not fulfil-able and it is not possible to realize tuneable white (i.e. light color especial for a day setting or rather a night setting).

Concept 1 features also some serious disadvantages: Probably there could arise problems with the room height and the aesthetical point of view is critical. And concept 1 is correlated to the highest costs (due to massive development costs) and it is with a residual risk due to product development process.

During the consortium meeting on January 16th 2013 in Dornbirn all concepts were discussed in detail among the whole consortium and it was decided to follow concept 2

"Pendelleuchte" as compromise between best lighting performance and lowest material costs.

Concept 2 "Pendelleuchte" fulfils mainly the Guiding Light requirements but is also correlated with development efforts due to the product development of the centrepiece "Pendelleuchte".

Remark:
During the detailed elaboration of concept 2 (=final concept) and in parallel the start of planning of the first field test apartments concept 2 was optimized: BLL agreed to expand the development effort of the "Pendelleuchte" to a whole luminaire portfolio in order to fulfil also all Guiding Light requirements in sleeping- and bath room (i.e. the use of light field was compensated). The final light concept is attached to the annex and is an essential part of the total Guiding light description ("deliverable D3.1 Solution package description").

2. Sensor technology

Mobility is essential for independence as well as ensuring good health and quality of life. Generally, mobility is impaired with older people, so, for the most part, they are unlikely to engage in vigorous activity (Alpini et al., 2000; Härlein et al., 2012). Furthermore, ageing goes along with non-directional mobility, inability to structure everyday life, and repeating, stressful questions to caregivers (Moffat, 2009). To proof the thesis and evaluate effects of Guiding Light on the participant's mobility, structure of daily activites and on circadian rhythm, a monitoring system based on several sensor related parameters is necessary. We differ between sensors for monitoring

- Activity and mobility in general
- Activities of daily living
- Persons location inside the residence
- Persons location and movement outside the residence
- Number of people inside the residence
- Ambient and room parameters

2.1. Activity and mobility monitoring

For monitoring a person's activity there are several approaches we considered and compared. A body worn device tracks the physical activity inside and outside the residence and is highly accurate in documenting steps and distance walked. Although, most of the tracking devices have filter mechanisms implemented on a hardware basis, which can prevent the devices from tracking single and minor movements. Therefore single steps are not tracked. This is because the focus of those tracking devices is mainly to monitor health relevant activity. For the purpose of Guiding Light it might be necessary to track also minor movement for measuring also small changes in activity and mobility.

We evaluated different body worn sensors, which are available on the market. All of them calculate steps out of data from three-dimensional accelerometers. Some of them require registering an account on the vendor’s software platform. There are public APIs available to access the basic data generated from the sensors. More detailed levels of data were available on specific requests. Due to our relationship in former projects we had access to the sensors and specific APIs before the devices were available on the market.

Activity Sensor	Radio technology	Public API	Extended API	Direct Access
Withings Pulse	Bluetooth Smart	Yes	Yes	No
Fitbit One/Zip/Flex	Bluetooth Smart	Yes	Yes	No
J’Style JP-1303	Bluetooth Smart	No	No	Yes
smartLAB walk+	ANT+	No	No	Yes

Fig. 14 Table with comparison of body worn activity trackers

Body worn sensors have the advantage of providing a continuous monitoring of activity over the day inside and outside of the residence as long as the sensor is strictly attached somewhere to the user. Supported ways of wearing the trackers are via clip on a belt, in the trousers pockets, on the wrists, as necklace, via clip on the bra or in a handbag. They are used in a wide array of applications which include fitness or sleep-monitoring (see Ancoli-Israel et al., 2003), and could therefore also be well fitted for the purpose of identifying a daily structure.

Fig. 15 Samples of body worn activity trackers (smartLAB walk+, Fitbit Flex, Withings Pulse)

However, traditional accelerometer-based activity sensor devices have two major practical drawbacks: First, they have to be worn by the persons, mostly on a specific location like wrist, a belt, a foot-strap or in/on a shoe. Unfortunately, often persons don’t like to wear such sensors or simply forget to put them on. Also these devices need care on the user’s part, like charging them regularly. Second, while such sensors have very good resolution (typically sampling rate up to 20 Hz and acceleration in 3 axis) and a wide array of research has already been done on extracting information out of such signals (e.g, see Bosch et al., 2012), they don’t tell in what location and context an activity was happening. One solution to the latter issue would be to add a separate tracking system that records where a person has been at specific times inside the apartment. By combining both information streams, some form of a daily structure could then be retrieved. However, the compliance issue mentioned in first place would still exist.

An alternative approach of measuring activity is possible by using room sensors. The data is documented automatically without any action necessary from side of the user. Possible sensors for activity monitoring are passive infrared sensors (PIR sensor) which are commonly used in motion detection. The primary use cases for those types of sensors are automatically activating lighting systems and burglar alarms. For activating artificial lighting most PIR sensors are equipped with ambient light sensors, which are also useful for the setting of Guiding Light.

Fig. 16 PIR sensors Thermokon SR-MDS BAT (left and middle), Merten ARGUS Presence (right).

We tested mobility monitoring by means of embedded room sensors and miniaturized sensors carried on the body. The use of sensors in buildings should be possible with normal techniques and at relatively low cost. In our example each room consists of a motion detector with a detection angle of 360°. The 360° detection angle is divided into four sectors with independent passive infrared sensors for each sector. The sectors are 90° each and can be parameterised individually. For each movement sensor the range, timing, and the sensitivity can be set for each block via parameters.

The next figure shows motion patterns for one week in three different rooms of senior's flat (four sectors per room) and corresponding overall activity measures per day/night on the top. Activity measures for day and night result from aggregation of all sectors of motion sensors in living room, sleeping room, and bathroom/toilet room of older persons within relevant time period. Night time period has be defined starting at 10 o`clock p.m. and ending at 5 o`clock a.m., following by day time period up to 10 o`clock p.m. The first person (apartment no. 5) has been diagnosed with temporal disorientation (following Mini-Mental-State Examination). The second person (apartment no. 6) shows normal spatio-temporal orientation. According to this diagnosis the overall mobility profile of the first person shows less overall intensity and more night activity in relation to day activity than the second person. Second person shows well structured history in activity in sleeping room with highest motion intensity in the morning.

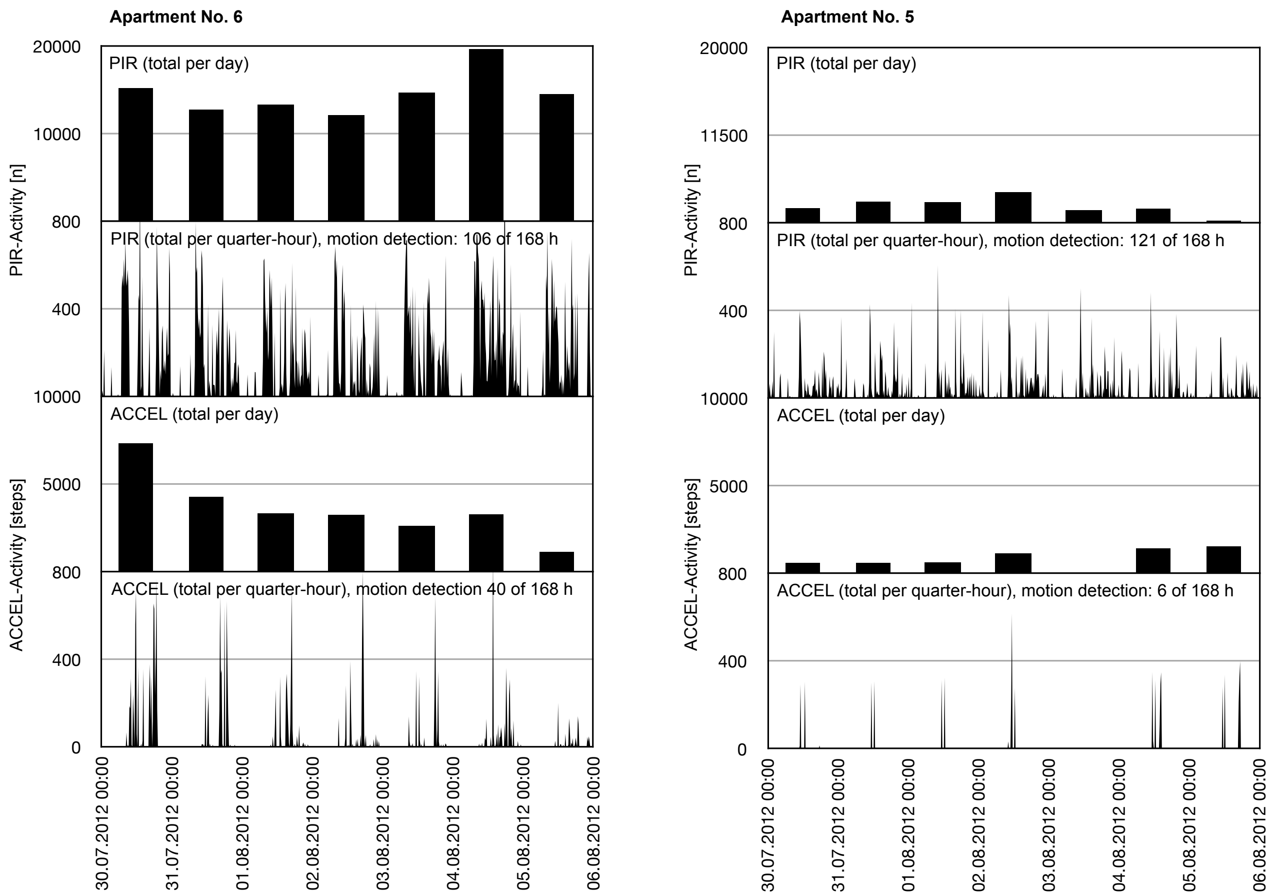


Fig. 17 Comparison of data quality of PIR sensors and actigraph.

Both persons spend, however, nearly same time inside their apartment of same size. Additional mobility monitoring is performed in the form of trend analysis, pattern discovery, and association rules which is applied to data obtained from unobtrusive sensors to capture comprehensive information about what, where and when residents are performing different activities of daily living. Results from continuous monitoring are used for intelligent light control system and to derive certain measured values of individual mobility (e.g. general motility, dynamics of body movement, and distances in indoor as well as outdoor locomotion).

To support the use case of activity monitoring in Guiding Light, a high sampling frequency is necessary. Most of the common PIR sensors, especially those with wireless technology, have sleep intervals of at least 60-90 seconds to reduce power consumption and because the default use case (activating lighting) doesn't need any action within a certain time frame after a person entered the detection area. For activity monitoring the requirement is to have a sampling frequency of 0,1 Hz or faster, which made the process of finding proper sensors challenging.

PIR sensor	Sampling Frq / Sleep time	Light Sensor	Sectors	Wireless	Power
Merten KNX Argus Päsenzmelder	1 Hz / 1 sec	10-2000 lx	4	No	220 V
Thermokon SR-MDS BAT	> 0.1 Hz / +60 sec	0-510 lx	1	Yes	3 x Lithium battery, 3,6V
Thermokon SR-MDS BAT modified	~0.2 Hz / 5-10 sec	0-510 lx	1	Yes	3 x Lithium battery, 3,6V

Fig. 18 Table with comparison of PIR sensors

Figure 18 shows the differences of the final types of evaluated PIR sensors. Since most of the flats acquired by the Guiding Light members are already in use (not newly built), it is highly recommended to avoid disturbance of the residents due to the installation of the system. Therefore a radio based bus system and compatible sensors is preferred. The costs for the installation are also lower if there is no need for installing a cable system to connect sensors to the building management system.

2.2. Activities of daily living

There are different approaches for monitoring of activities of daily living (ADL). The focus on sensor research had again the requirement of finding unobtrusive ways of implementation and usage. There are sensors with radio transmission (EnOcean) that can be attached to specific furniture (e.g. a chair, a sofa) and send a telegram as soon as some pressure is detected by the sensor. Though in most cases the sensors have to be installed to the inside of the furniture.

Fig. 19 Sensor examples for monitoring ADL: wireless pressure sensor for installation into furniture, wireless reed contact for door and window monitoring, S0 connected electricity sensor (www.sensocasa.de)

Other sensors can be attached to objects for sending information about their usage. Reed contacts can trigger information about window and door activities (status: open/closed). They can also be useful to increase the accuracy of PIR sensors. Especially if a person leaves the residence the sensor can show if the main door was openend after the PIR sensor in the near of the entrance was activated to have a high chance that the person left the room.

Another approach is to monitor energy usage in the housing (water, electricity, gas etc.). There are several sensors available. The installation has to be done by an electrician directly to the power source. The benefit has to be questioned, since the power consumption is mostly no direct indicator for specific ADL. If the monitoring is attached to specific devices (e.g. power consumption of TV), the information can be more specific (Fig. 19).

2.3. Location tracking and people counting

Knowing about the individual daily structure of an inhabitant is a key requirement for providing such a lighting system. Besides interviews as basic information source for identifying such a daily structure, an automatic way of discovering changes to this structure is needed to allow for automatic or manual adjustments as well as ongoing evaluation purposes for the lighting system. For the exact evaluation of a single person's activity, location, ADL and habits it is necessary to know the exact position of that person inside the residence and if possible also outside.

Generally the goals for such systems are to receive information such as number of occupants, identification of occupants, physical activity of occupants, and localisation of occupants in a room. In the following figure various known methods and devices for presence detection and person identification are reviewed.

Type of sensors	Information grade/ Resolution	Information					Price	Main problems
		Movement detection	Number of occupants	Persons identification	Persons localisation	Physical activity		
Passive-IR	Low	+	-	-	-	+/-	low	low resolution
Light barriers	Low	+/-	+	-	-	-	low	low resolution
Microwave detectors	Low	+	-	-	-	-	medium	low resolution and relative high price
Ultrasonic (simple)	Low	+	-	-	-	-	low	Low resolution
Ultrasonic (intelligent)	Relative low	+	+/-	-	+/-	+/-	medium	Low price/ information grad relation
Shock sensors	High	+	-	-	-	+/-	medium	Relative complexity installation
IR Camera	Very high	+	+	-	+	+	very high	Very high price
360° PIR	Very high	+	+	-	+	+	medium	Mechanic noise
Trans-ponder	Low	-	-	+	-	-	medium	Low information grade, low range
Video camera	Very high	+	+	+/-	+	+	high	Complexity of algorithms, psychological factors, critical to insufficient light
Biometric systems	Low	-	+	+	-	-	high	Low information grade, psychological factors

Fig. 20 Comparison of presence detection sensors (from Ivanov et al., 2002)

We evaluated different approaches of location trackers. During that evaluation we were in contact with experts for sensor technology, people counting and location system and for GPS tracking. Different approaches were compared and considered. The most accurate approaches are based on optical systems (stereoscopic cameras). At least two devices have to be installed per room to have enough coverage. The stereoscopic cameras take pictures frequently. Those pictures are processed by image recognition software. The software then identifies objects.

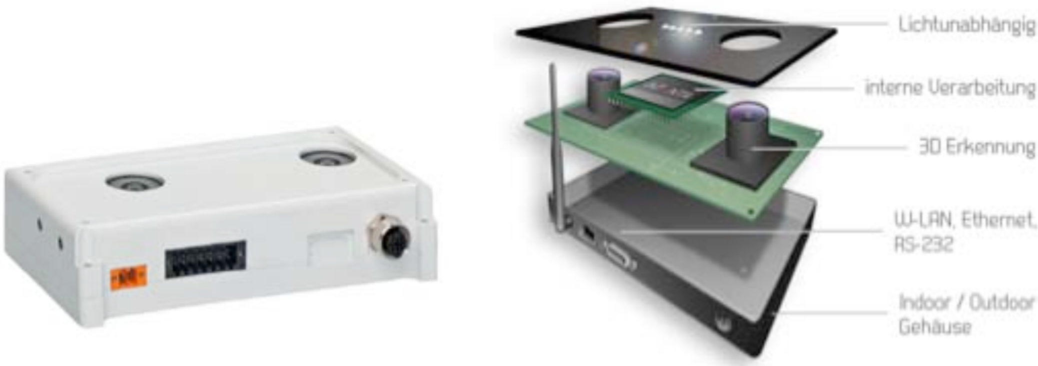


Fig. 21 Location tracking with stereoscopic cameras from Crosscan (left) and Intenta (right)

Specific algorithms based on images from different angles containing the same objects can define exact location within the room. The analytics software can also retrieve additional information. The detection on objects and persons is also possible without any movement.

Fig. 22 Single room coverage by an optical system (example: Intenta)

Another solution for location tracking of people are thermal sensor arrays. We tested IRC300 series from Irisys originally used as people counter. With IRC3010 imaging optics, sensor, signal processing and interfacing electronics all contained within a moulded plastic housing. The unit is used in a downward looking manner, as the sensor functions optically seeing the heat emitted by people passing underneath as infrared radiation, collected through a germanium lens with a 60° field of view. We tried to use orginaly array signal to detect the location of a person in a room. However, the main disadvantage of this solution are the very high costs of 1.600,- Euro per unit.

Fig. 23 Thermal sensor array Irisys IRC3010 IP.

In an attempt to retrieve activity information in a way that doesn't require a participant to wear sensors and at the same time yields approximate information about the participant's location inside the apartment, we investigated the fitness of standard passive infrared (PIR) presence sensors for such a purpose. PIR-sensors typically yield on/off signals depending on the presence of humans (or, more precisely, depending on location changes of heat sources similar to human bodies) and are slow in reporting their status compared to accelerometers. However, by combining multiple sensors to cover relevant sectors in an apartment and by recording each sensors actuations it is possible to deduce some form of daily activity in an apartment (compare to Lymberopoulos, 2008). Even though the information delivered by the sensors itself is basic, by aggregating and relating sensor-actuations, one can get activity measures within a sector for a specific time period (e.g. number of actuations, duration of the on-phase), or sequences of actions among multiple sectors (e.g. person moves from the bed-room to the toilet an back).

In a small field test we investigated the basic applicability of this idea in a real world context. For this we equipped two apartments of two single elderlies with PIR sensors and a data logging facility. Figure 23 shows the room setup with a total of 12 PIR sectors. Each room was equipped with one offering four sections of detection and a minimum detection-interval of one second between actuations.

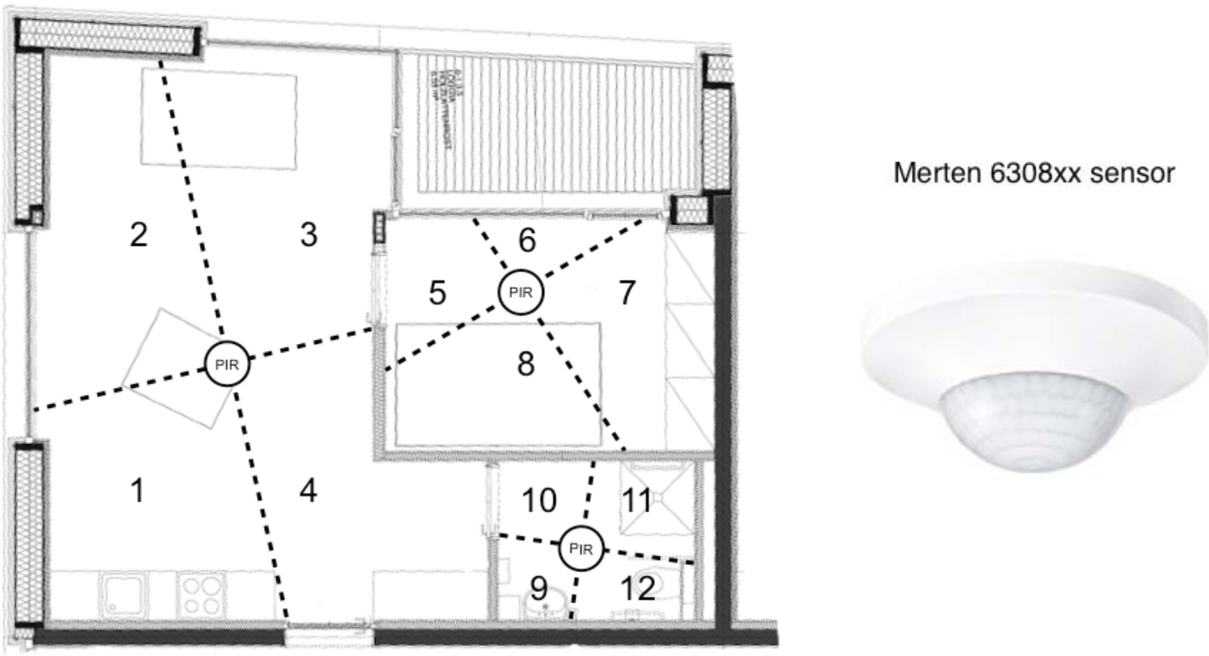


Fig. 24 Plan of test apartment with numbered PIR-sensor sections (total 12 sections).

To see if we could deduce daily structure parameters from the logged data, we evaluated data collected over a period of 6 month. Figure 24 shows a daily activity profile of four PIR-sectors in the living room on sundays averaged over 6 month. The x-axis shows the time whereas the y-axis the number of individual activations in a sector per 15 minutes time slot. One can clearly see the lack of activity from 11:45 to 12:15 hinting at a lunch break.

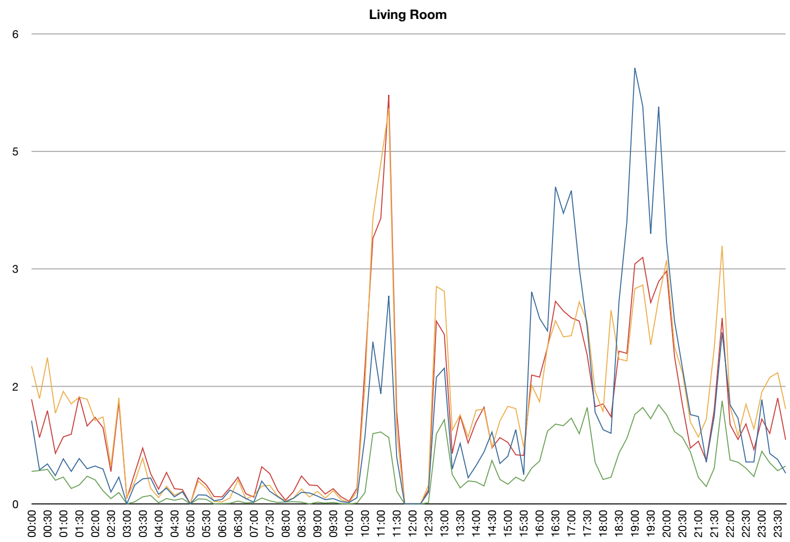


Fig. 25 Activity profile of the 4 PIR-sectors in living room for sundays averaged over 6 month.

Figure 25 shows a daily activity profile for two typical days for one apartment. The maximum activity distribution in the separate sectors of the apartment indicate different daily actions on weekends (left side) and weekdays (right side). The x-axis shows the time whereas the y-axis shows the sector-number. Data for this chart has been aggregated over a period of 6 month.

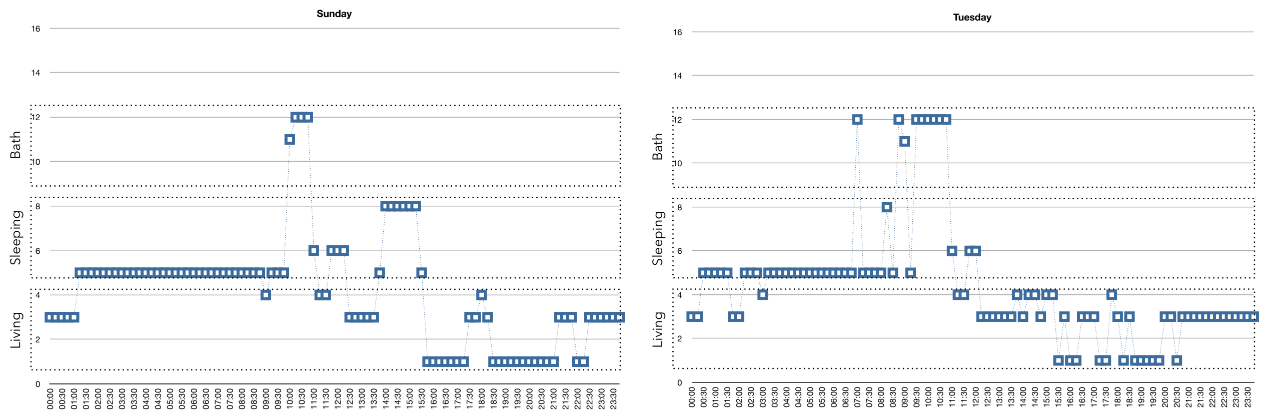


Fig. 26 PIR sector with maximum activity in a time slot of 15 minutes. A comparison between a typical Sunday and Tuesday (averaged over 6 months) show a shift in sleep time by half an hour earlier during weekdays.

Another interesting question was if there would be some detectable change within the daily activity profile between summer- and winter-months, as this is especially relevant in an application using light. Figure 26 shows a shift in sleep/wake times during two summer months and two winter months, meaning this system can in fact be used for detecting changes to the daily structure of a person, without the need for the person to wear or maintain any sensors at all.

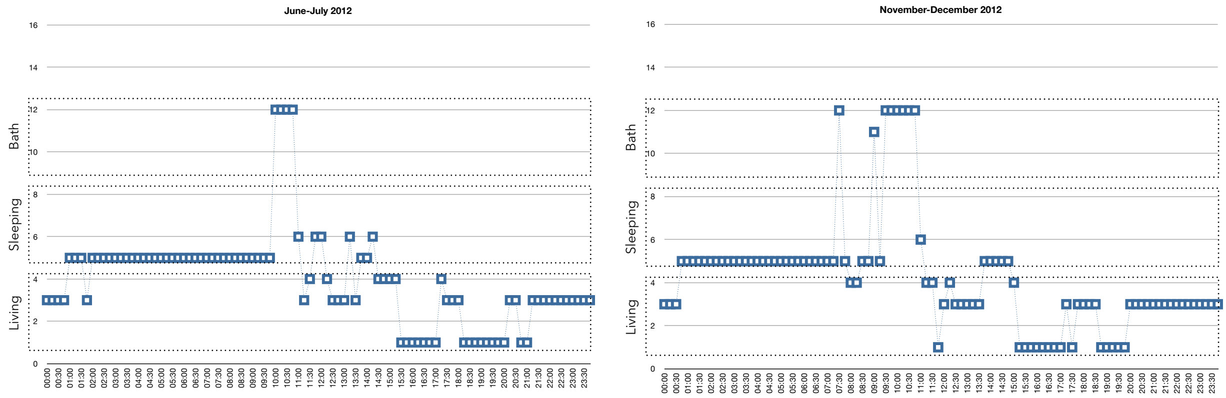


Fig. 27 PIR-sector with maximum activity in a time slot of 15 minutes. A comparison between summer and winter periods shows a shift of sleep-time by 15-30 minutes earlier in winter.

Among the parameters that can be deduced from activity data we recorded in this field study are sleep-/wake times (indicator of circadian rhythm), the time at which various sectors of an apartment feature the most presence (and therefore might be candidates for special light treatments), nightly actions like visiting the toilet or getting something from the kitchen, or the time at which a participant leaves the apartment or comes back (e.g. for getting lunch), and many more.

Despite these promising results, there are two obvious major drawbacks of this PIR-sensor based approach: First, it’s only suitable for single person households without pets. Any additional heat-sources would cause additional actuations not related to the main person’s actions. In our case, one workaround for this could be to automatically track situations where more than one person is present (e.g. by light barriers that allow for people counting at the entrance, or by observing other room parameters like CO2 levels) and exclude those from data evaluation.

Second, activity that’s happening outside the apartment that might have a big effect on a person’s health state cannot be tracked in this way. One way to overcome this issue would be to have optional wearable accelerometers that could deliver additional input when worn, but with the core system remaining still functional without them. In the Guiding Light project, we intend to use both solutions to these two drawbacks mentioned here.

As a result we decided to use a cost effective and enough accurate solution based on wireless PIR sensors and wireless door contacts (reed contact).

	Camera based system	**Thermal sensor array**	**PIR sensor system**
Detection without movement	Yes	Yes	No
Behaviour analysis possible (sitting, standing, types of movement etc.)	Yes	No	No
Independent from body temperature	Yes	No	No
Filtering of pets	Yes	No	No
Location accuracy	< 20 cm	Once per sensor	Once per sensor or sector
Easy installation (no experts necessary)	No	Yes	Yes
Wireless	No	No	Yes
External processing possible	No	Yes	Yes
Privacy compliance (no storing of images etc.)	No	Yes	Yes
Sensors per room	3-4	4 or more (depending on ceiling or wall mountage and sensor type)	1-3
Ready to use (no additional software development)	Yes	No	Yes
Costs per sensor (approx.)	1.200,00 EUR	50,00 EUR + Controller each sensor	200,00 EUR
Costs per flat (approx., excl. additional sensors/gateways)	6.500,00 EUR	600,00 EUR + development	1.200,00 EUR
Example	Intenta	Panasonic Grid-Eye	Thermokon SR-MDS

Fig. 28 Comparison of camera based system with PIR sensor system for location tracking, people counting and activity monitoring

For people counting we evaluated different systems available on the market and found some difficulties using those approaches. Due to the importance of having the exact number of persons inside the flat, we need a system that is highly accurate.

A common approach is to use a light barrier system. When using two parallel mounted light barriers a passing person can trigger two different timestamps from the barriers, which can be taken to know the passing direction. This requires a highly accurate timing synchronization of both barriers and a timestamp with milliseconds resolution.

It can be difficult though to install the system directly at the main door. It has to be powered and should be installed directly inside the doorframe to avoid triggering by just moving along the entrance area. If some object passes the light barrier (bag, wheeled walker, suitcase) it can lead to false counting.

The tracking of people outside the flat is possible on basis of GPS tracking. For inside tracking there are additional systems possible besides the systems described based on optical systems and thermal sensor arrays. We evaluated some systems available on the market and had contact with the company Fidelak GmbH, which offered to build some specific sensor for the need of Guiding Light.

	Complexity	**Costs**	**Remarks**
Radio technology (based on intensity of transmission and triangulation)	High	High	
Runtime measurements based on ultrasonic	High	High	
Pressure sensors in floor mat	Moderate	High	
RFID	Moderate	Moderate	People or clothes have to be tagged

Fig. 29 Overview of solutions which dropped out by complexity or costs

Fidelak offered a very promising sensor for acceptable price range. The sensor would have GPS monitoring with included M2M transmission (Machine-to-Machine based on GPRS and embedded SIM card). Additional sensors like acceleration (activity), light sensor, temperature, pressure (altitude) were possible. The initial batch could be available 3-4 weeks after start of the project. Main development was offered for 6.000,00 EUR and about 400,00 EUR per device (with 20 devices in total).

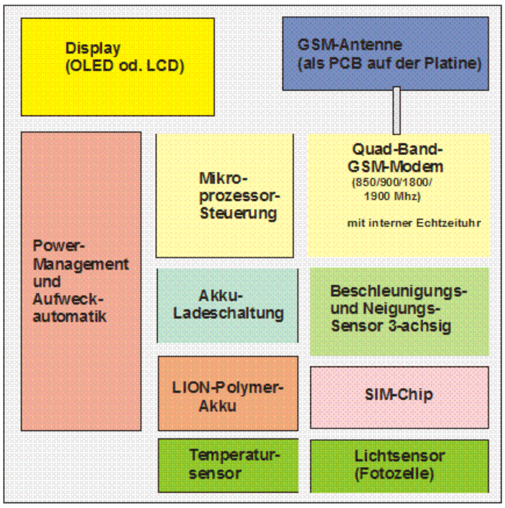


Fig. 30 Example of an individual sensor device and the components (source: Fidelak)

The reason we didn't go ahead into that direction was mainly the obvious problems with compliance for any body worn sensor. If the user forgets to apply the sensor, no data would be collected and the evaluation of any progress or impact is not possible. Therefore the best possible solution was to focus mainly on room attached sensors.

2.4. Overview of possible and selected sensor parameters

Several arguments were considered in the process of choosing the final setting of sensors and parameters. The main aspects were:

- Reduce the costs
- Keep up good system usability
- Provide maximum compliance
- Reduce complexity (in terms of validation, development if algorithms etc.)
- Support an easy communication and argumentation (dissemination/exploitation, market)
- Keep the system as simple as possible (focus on market product, simple products can be sold more easily)
- Extendibility (modularity, system can be extended by modules)

	Accepted	Reason for exclusion	Remark
Lighting exposition (body worn)	No	Compliance	
Activity (body worn)	No	Compliance	
Position (body worn)	No	Compliance	
Activity (room mounted)	Yes		
Position (room mounted)	Yes		
Additional **vital signs** (heart rate, blood pressure, weight, blood sugar, brain activity etc.)	No	Compliance, low importance	
Sleep	(Yes)		By inquiry and PIR
Eating, drinking	No	Complexity	
Mood	(Yes)		By inquiry
Energy, drive	(Yes)		By inquiry
Lighting situation (brightness)	Yes		By photo diode integrated into PIR sensors
Ambient **room parameters** (temperature, humidity, CO2)	No	Costs, low importance	
Energy consumption (water, gas, power)	No	Costs, low impact	
Weather	No	Low importance	

Fig. 31 overview of possible sensor values and final selection

3. Gateway

The Guiding Light control algorithm is installed on a web-server ("Cloud") and the Guiding Light system within the apartment is connected via gateway with the internet. For data communication between lighting and sensoring technology as well as central processing unit we are looking for a network node that can operate at any network layer. As for many receivers the information can be transmitted via the corresponding communication interface (LON, EIB/KNX, RS485 Modbus, RS485 EVC, Ethernet, BACnet, EnOcean...) on bus level. Our solution should work with radio sensors, respectively keys, based on

EnOcean RF technology and controllers, respectively control systems, with Ethernet interface.

Within our project we have to build on a very flexible solution, because Guiding Light should be open to different building management systems. We distinguish between wireless solutions and will use EnOcean in this case. The EnOcean technology is an energy harvesting wireless technology that combines micro energy converters with ultra low power electronics and enable wireless communications between batteryless wireless sensors, switches, controllers and gateways.

3.1. EnOcean-Gateway without backup storage

We are testing Thermokon STC-Ethernet, a bidirectional gateway (with Ethernet interface) for sensors, switches and actuators, based on EnOcean technology and controllers, respectively control systems with Ethernet interface, communicating via TCP/IP or UDP. As the radio signals are electromagnetic waves, the signal is damped on its way from the sender to the receiver. That is to say, the electrical as well as the magnetic field strength is removed inversely proportional to the square of the distance between sender and receiver. Beside these natural transmission range limits, further interferences have to be considered: Metallic parts, e.g. reinforcements in walls, metallized foils of thermal insulations or metallized heat-absorbing glass, are reflecting electromagnetic waves. Thus, a so-called radio shadow is built up behind these parts.

Fig. 32 Thermokon STC-Ethernet Gateway

Thermokon STC-Ethernet does not have a backup storage for control algorithms. One of our Guiding Light versions needs a 2-way client-server connection, where all sensors and actors are clients which communicate via a wirleless internet connection with a cloud-server. In case of connection problems to the internet, there is no connection to control algorithms and sensor data storage.

3.2. EnOcean-Controller with backup storage

In order to cope with this problem we will also use an EnOcean controller with backup storage. Normally, 2-way client-server communication is provided via internet from sensors and actors as clients and cloud data storage as server. In case of connection problems to the internet a local controller takes over the control and monitoring resp. data storing. As soon as internet connection is rebuilt, local controller transfers sensor data to cloud server from backup storage and receives current control algorithms. This solution is not only important for temporary loss of internet connection but also for our exit strategy, when test persons are no longer interested in using cloud services.

We are testing next.controller from AutomationNext which can be used as a central control unit for buildings. This gateway is equipped with a backup storage in order to ensure the basic Guiding Light function in case of connection problems to the internet. We obtain redundancy via data logging on SD card and wireless connection via external EnOcean gateway.

Fig. 33 next.controller from AutomationNext.

3.3. Embedded IPC control unit

In some cases we would prefer cable based bus systems, e.g. when radio technology does not work properly due to high data transmission or radio waves are not be transmitted. There are two relevant bus protocols: KNX EIB and DALI. KNX EIB uses shielded twisted pair cables, through which the signal as well as 30V DC link power is transferred. For data transmission, a balanced baseband signal coding is used with a baud rate of 9600 bits per second. The Digital Addressable Lighting Interface (DALI) is an interface definition in building automation for the transmission of control signals for lighting devices. DALI ballasts are wired in parallel and linked with one another via the controller.

In this case client-server communication is accomplished via an embedded IPC control unit. We are testing embedded IPC series C1010 form Beckhoff. With a 500 MHz Pentium MMX-compatible processor it offers average CPU performance. While the resulting control system has no visualisation, it does have communication capability via the built-in Ethernet interface. The modules of the CX series system are connected with each other via the standardised PC/104 bus (16 bit). The individual system components are modules with a width of 19 mm (single) or 38 mm (double) that can be arranged in series. The basic unit consists of a CPU (CX1010) module and a power supply module (CX1100-000x).

Fig. 34 IPC CX1010 from Beckhoff.

3.4. Overview

We might follow up all mentioned solutions, because we will probably find very different situations within older people homes. Nevertheless, we will select solution with most advantages in specific situation. For most mentioned components there exist more powerful versions and there are different manufactures which offer similar technological solutions.

	Data communi-cation	Costs	Loss of control data	Loss of monitoring data	Remarks
Gateway without backup Thermokon STC-Ethernet	Wireless (EnOcean)	Low	Possible in case of connection problems to the internet	Possible in case of connection problems to the internet	
Controller with backup AutomatioNext next.controller	wireless or cable based	Medium	No, because of backup storage	No, because of backup storage	SD card
Embedded IPC control unit Beckhof CX1010	cable based	High	No, because of local control unit	No, because of local control unit	Local server

Fig. 35 overview of possible gateways/controllers.

4. References

Alpini, D., Cesarani, A., Pugnetti, L., Mendozzi, L., Cardini, R., Kohen-Raz, R., Hahan, A., & Sambataro, G. (2000). Project to prevent mobility-related accidents in elderly and disables. Proceedings of 3rd International Conference about Disability, Virtual Reality & Associated Technologies, Alghero, Italy.

Ancoli-Israel, S., Cole, R., Alessi, C., Chambers, M., Moorcroft, W. & Pollak, C.P. (2003). The role of actigraphy in the study of sleep and circadian rhythms. American Academy of Sleep Medicine Review Paper. SLEEP 2003;26(3):342-92.

Bosch, S., Marin-Perianu, R., Havinga, P.J.M., Horst, A., Marin-Perianu, M. & Vasilescu, A. (2012). A study on automatic recognition of object use exploiting motion correlation of wireless sensors. Personal and Ubiquitous Computing, 16, 875-895.

Chang, Y.-J., Peng, S.-M., Wang, T.-Y., Chen, S.-F., Chen, A.-R., Chen, H.-C. (2010). Autonomous indoor wayfinding for individuals with cognitive impairments. Journal of Neuroengineering and Rehabilitation, 7/45, 2-13.

Chung, J., Kim, I.-J. & Schmandt, C. (2011). Guiding Light: Navigation Assistance System Using Projection Based Augmented Reality. Paper presentation at International Conference of Consumer Electronics, Las Vegas.

Figueiro, M.G., Plitnick, B., Rea, M.S., Gras, L.Z. & Rea, M.S. (2011). Lighting and perceptual cues: Effects on gait measures of older adults at high and low risk for falls. BMC Geriatrics, 11, 2-10.

Guiding Light Consortium (2012). Deliverable 1.1: Medical, psychological, and technological framework.

Härlein, J., Halfens, R. J. G., Dassen, T & Lahmann, N. A. (2010). Falls in older hospital inpatients and the effect of cognitive impairment: a secondary analysis of prevalence studies. Journal of Clinical Nursing, 20, 175-183.

Lymberopoulos, D., Bamis, A., & Savvides, A. (2008). Extracting spatiotemporal human activity patterns in assisted living using a home sensor network. In Proceedings of the 1st international conference on Pervasive Technologies Related to Assistive Environments. 29.1-29.8. New York: ACM.

Moffat, S. D. (2009). Aging and Spatial Navigation: What Do We Know and Where Do We Go? Neuropsychology Review, 9, 478–489.

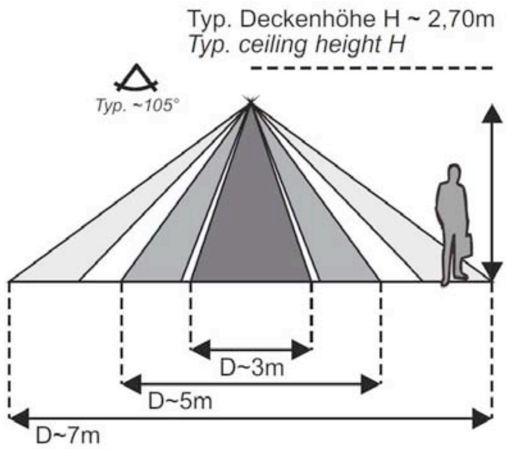
Rea, M. S., Figueiro, M. G., Bierman, A. & Bullough, J. D. (2010). Circadian light. Journal of circadian Rhythms, 8, 2-3.

Stripling, A. M. (2008). Ambient light and sleep in community dwelling older adults. Zeitschrift für Gerontologie und Geriatrie, 33/3, 155-168.

Veitch, J.A. & Galasiu, A.D. (2012). The physiological and psychological effects of windows, daylight, and view at home: review and research agenda. NRC-IRC Research Report RR-325.

Annex: PIR sensor analysis

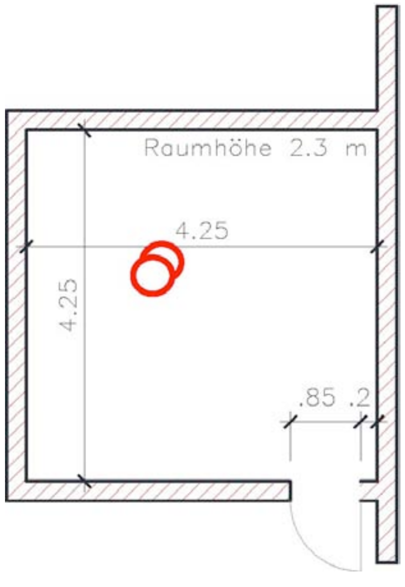
This work is done for characterizing passive infrared (PIR) motion sensor SR-MDS 315 MHz from Thermokon for AAL Guiding Light.



PIR Sensor SR-MDS 315 Mhz Erfassungsbereich lt. Datenblatt

ERFASSUNGSBEREICH PIR-SENSOR

Nahe dem Raumzentrum wurden an der Decke zwei PIR-Sensoren aufgehängt und die Anzahl der erfolgreichen Detektionen bei bestimmten Abständen notiert. Raummaße:

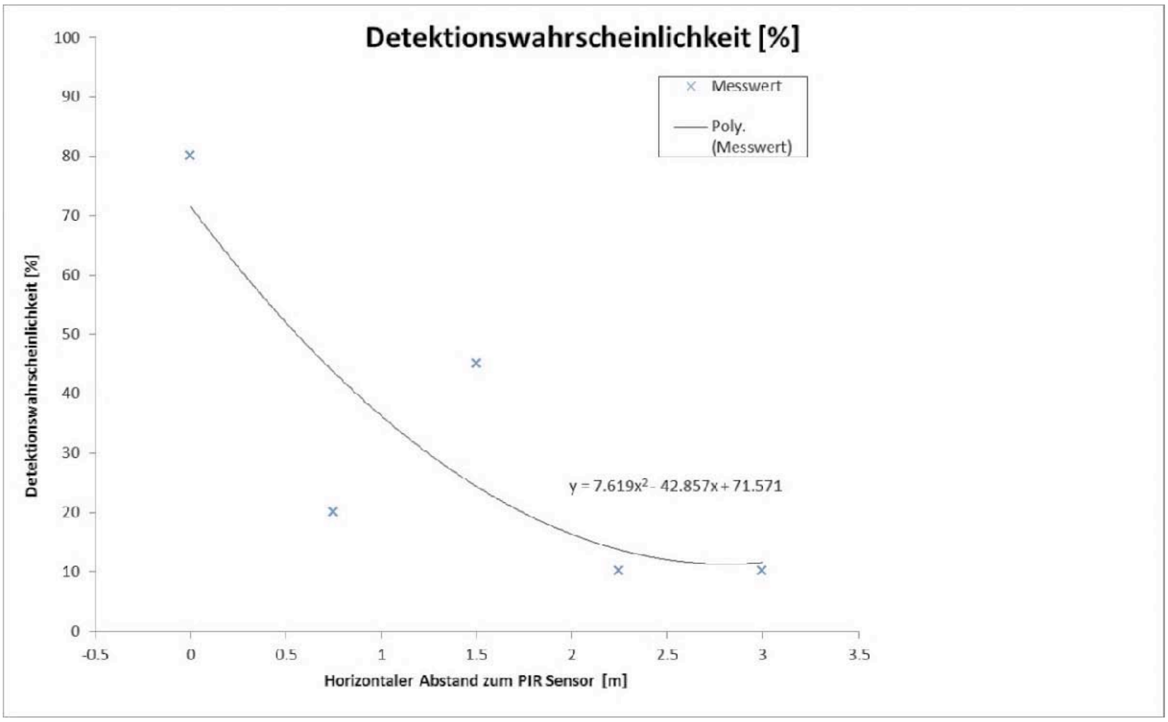


Theoretisch maximal erkennbarer Abstand, lt. Datenblatt:

$$x_{theo} = \text{Raumhöhe} * \frac{3.5}{2.7} = 3\ m$$

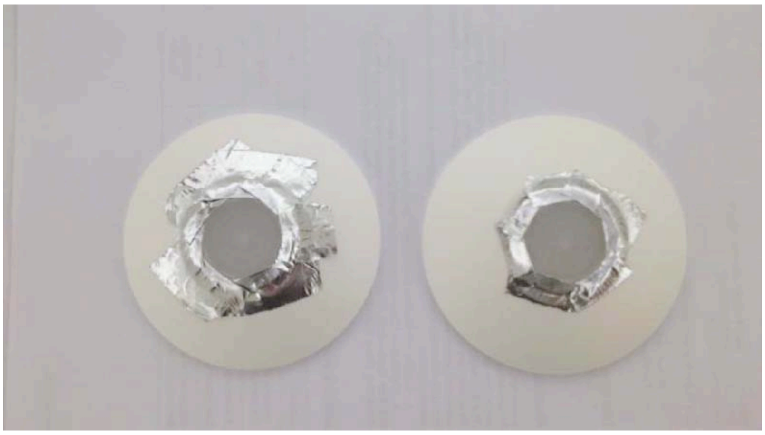
Erfolgreiche Detektionen n bei 10 Versuchen (gemittelt über zwei PIR Sensoren) für bestimmte Abstände zu dden Sensoren:

x_{theo}	$\frac{3x_{theo}}{4}$	$\frac{x_{theo}}{2}$	$\frac{x_{theo}}{4}$	0
1	1	4.5	2	8



SENSOR MIT AUßENRINGBLENDE

Mit einer Außenringblende (Metalltape, siehe Bild) scheinen die PIR Sensoren nicht mehr ordnungsgemäß zu funktionieren.



Erfolgreiche Detektionen bei 10 Versuchen (gemittelt über zwei PIR Sensoren):

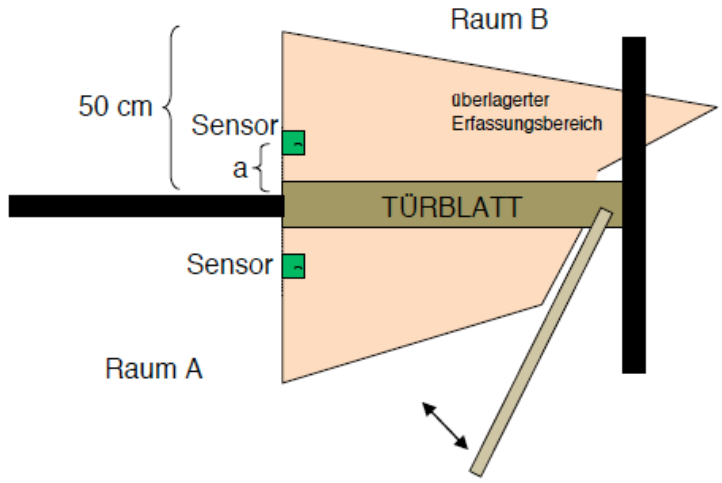
x_{theo}	$\frac{3x_{theo}}{4}$	$\frac{x_{theo}}{2}$	$\frac{x_{theo}}{4}$	0
0	1	0	2	1

HALB-ABGEDECKTER SENSOR

Im bedeckten Halb-Raum wurden keine Detektionen mehr festgehalten. Auf der anderen Seite ist aber ebenfalls ein sehr starker Einbruch der Detektionswahrscheinlichkeit zu erkennen. Diese Art von Blende ist praktisch nicht zu verwenden.

DETEKTIONSWAHRSCHEINLICHKEIT TÜRDURCHGANG

Die PIR Sensoren wurden ca. 15 cm von Tür entfernt an Decke angebracht. („Platzierung PIR-Sensoren, Lichtfunkschalter und Einbindung der TürkontaktSensoren.docx“)
Raum B

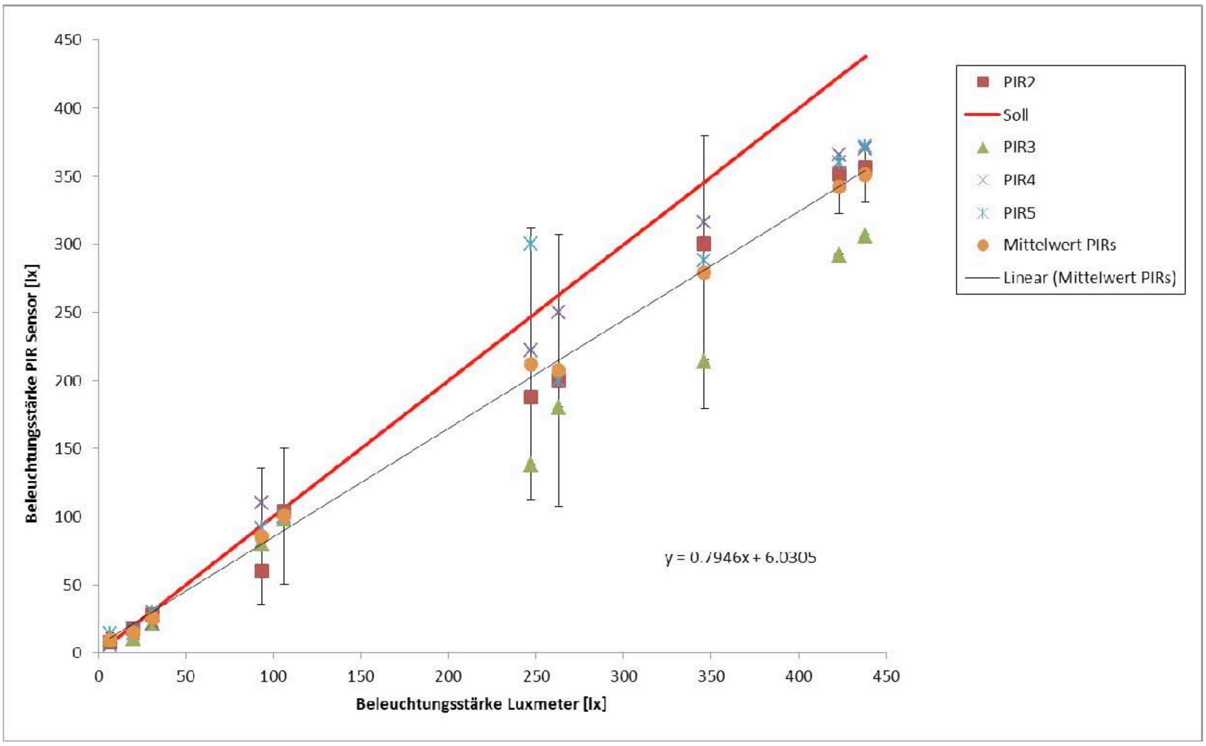


Die Detektionswahrscheinlichkeit liegt bei **100%**, wenn die Tür geöffnet und geschlossen wird. Auch stimmt die Reihenfolge der Detektionen. Zwanzig durchgeführte Türdurchgänge sowohl von Raum A nach Raum B, als auch umgekehrt konnten korrekt detektiert werden.

Wird die Tür langsam du urchschritten, ergibt sich eine Detektionsw wahrscheinlichkeit von ca. **92 %** (1/13 keine Detektion). Die Detektions-Reihenfolge der zwei PIR Sensoren stimmte bei **77 7 %** (3/13 Reihenfolge falsch) der Versuche.

VERGLEICH BELEUCHTUNGSSTÄRKE MESSUNG

Um die gemessene Beleuchtungsstärke der PIR Sensoren mit d dem tatsächlichen Wert (gemessen mit Luxmeter: testo 540) vergleichen zu könne en wurden diverse Messungen bei unterschiedlichen Beleuchtungsniveaus durchgef führt.



Im Bereich von ca. 70 – 4400 lx ergeben sich große Schwankungen in der Messung der Beleuchtungsstärke, so kann es sein das der angezeigte Wert der PIR-Sensoren um bis zu ± 10 00 lx schwankt.