Guiding Light

Ambient Light Guiding System for the Mobility Support of Elderly People

Field test report

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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 (**has produced**) 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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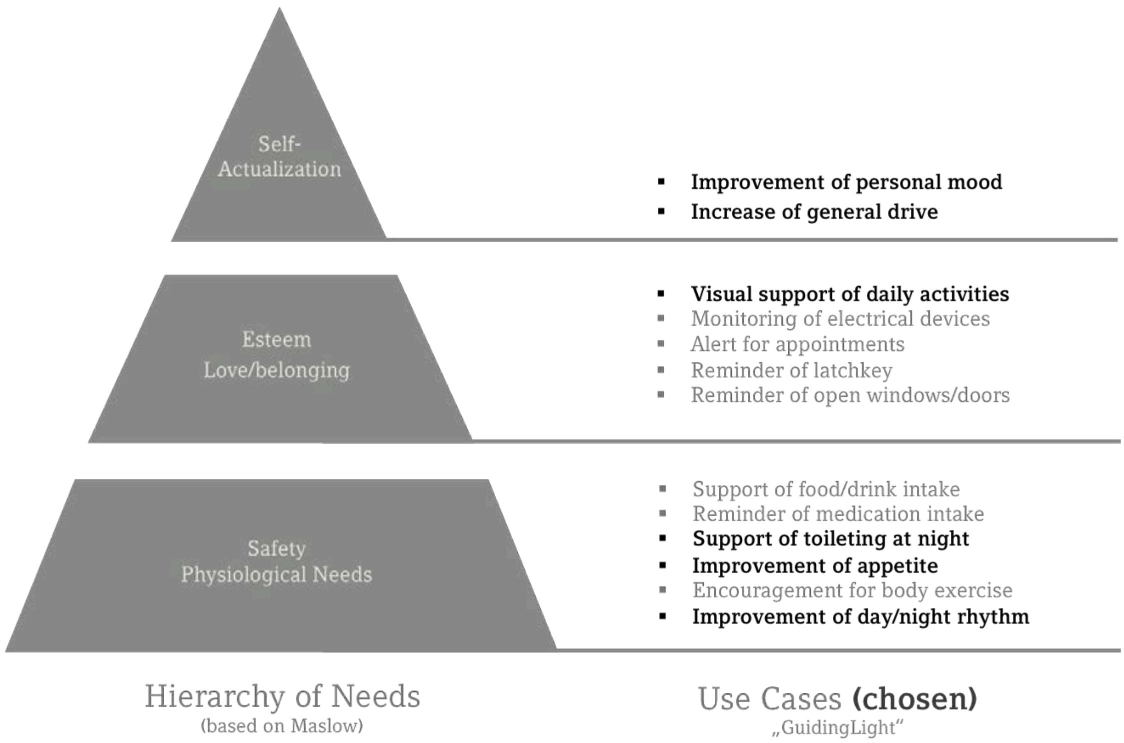
1. Introduction

Generally speaking, the aim of the Guiding Light project is to develop an intelligent lighting system that enhances the mobility of elderly people. In more detail, this means that we want to enhance the extent of activity and mobility by supporting a circadian rhythm with specific lighting parameters. Mobility is defined by purposeful movements, as opposed to a pointless wandering around as it can often be observed in the early stages of dementia (see e.g. Lai & Arthur, 2003[1]).

Based on several interviews with stakeholders (physiotherapists, care givers) performed at the beginning of the project, we learnt that mobility is not only directly impaired by medical motion restrictions, but rather by indirect effects of missing urge to move or pursue daily activities, or by a subdued mood elderly people suffer from (especially when living alone). Luckily, drive and mood can also be enhanced by light, so that the right lighting can not only improve orientation and chronology of actions during the day as direct influences on mobility, but also affects indirect mobility parameters. Figure1 illustrates the variables we decided to influence with the lighting system, showing that different levels of needs were addressed (as defined by Maslow, 1943). [2]



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[1] Lai, C. K.Y. and Arthur, D. G. (2003), Wandering behaviour in people with dementia. Journal of Advanced Nursing, 44: 173–182.

[2] Maslow, A. H. (1943), A theory of human motivation. Psychological Review, Vol 50(4): 370-396.

Figure1: Use Cases of the Guiding Light system, based on interviews with different stakeholders who were asked for leverage points to enhance the mobility of elderly people with lighting.

Hence, the **hypotheses** we want to test in our field trials (see the following sections) are as follows:

- **Temporal mobility:** By providing a perfect chronobiological indoor lighting (adapted to the inhabitant's individual needs), sleeping rhythm and sleep quality are enhanced.
  >> Measures: sleep/wake duration (PIR), sleep interruptions (PIR), subjective feedback on sleep, performance in temporal orientation test (baseline vs. endline)
- **Spatial mobility:** A stabilized circadian rhythm will enhance activity during the day
  >> Measures: number of stays in predefined areas of the flat (in accordance with perfect chronobiology) (PIR), extent of motion (PIR), performance in spatial orientation test (baseline vs. endline)
- **Indirect mobility parameters:** By providing optimal lighting conditions (light intensity, color, luminance, minimal glare and shadiness), the visual performance of daily activities is enhanced and croppers are diminished. Furthermore, subjective wellbeing and drive are improved (thus promoting mobility)
  >> Measures: data from interviews (baseline vs. endline), subjective feedback in repeated monitoring questionnaires (every other week throughout field trials), final interview on subjective experiences at the end of the field trials.

These hypothesized effects are summarized in Figure2, showing which light characteristics (task light vs. Ambient room light) are supposed to trigger which type of improvement.

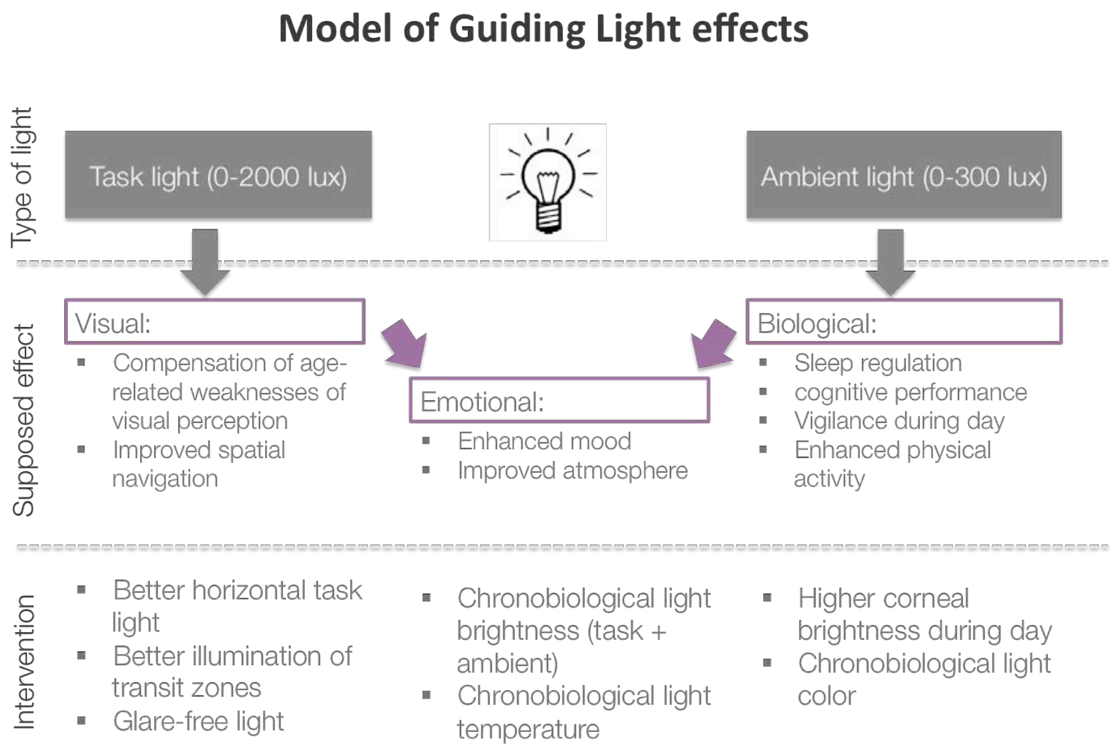

Figure2: Model of postulated effects of the intelligent lighting system "Guiding Light".

More details on the nature of the implemented light intervention can be found in Deliverable D3.1.

In the following chapter 2, the preparation of the field trials in terms of used evaluation metrics, experimental design and the characteristics of the sample are described. Chapter 3 describes the used light intervention (approach I and II), as well as the realized user interface oft he mobility monitoring. Afterwards, the results oft he field trials are presented, separately fort he two adpopted lighting approaches, as well as the iteratively realized improvements of the lighting system. In chapter 5, the overall conclusions of the field trials are discussed.

2. Preparation of Field Trials

2.1. Field trial design

The basic idea of the field trials was to test the effect of the guiding light system on the mobility of elderly seniors. Since the financial budget for the lighting equipment was limited and prototypes were more expensive than originally planned, we could only afford to install the guiding light system into 11 households: 4 in Austria, 4 in Germany, 2 in Italy and 1 in Switzerland (for details see the implementation report, D3.2).

In order to realize a more valid design, it was decided to include a control group of 8 households that were equipped with PIR-Sensors only, but not with any special lighting system

(5 in Austria, 1 in Germany, 2 in Italy). Details of the intervention and control group are described in chapter 2.3 and in Annex II.

The measurements included constant PIR monitoring of the activities within the flat, and a number of tests and questionnaires, as described in the following section. Regarding the psychological measures, participants were tested at the beginning of the field trials before the activation of the new lighting system (=baseline measurement). During the field trials, when the parameters of the lighting system were constantly changed / adapted to the inhabitants, all participants were asked to answer a selection of the test items via an online-questionnaire approximately every other week for the duration of the whole field trial. Field trials started in October 2013 at earliest (for most of the participants in summer 2014) and lasted until March 2015. [3] For each participant, 13-24 different light programmings could be realized.

At the end of the field trials, the complete test battery of the beginning was run through again (=endline measurement) to see if there were some relevant changes between the beginning and the end of the field trials. The sequence of the different test types for the intervention and the control group is displayed in Figure3.

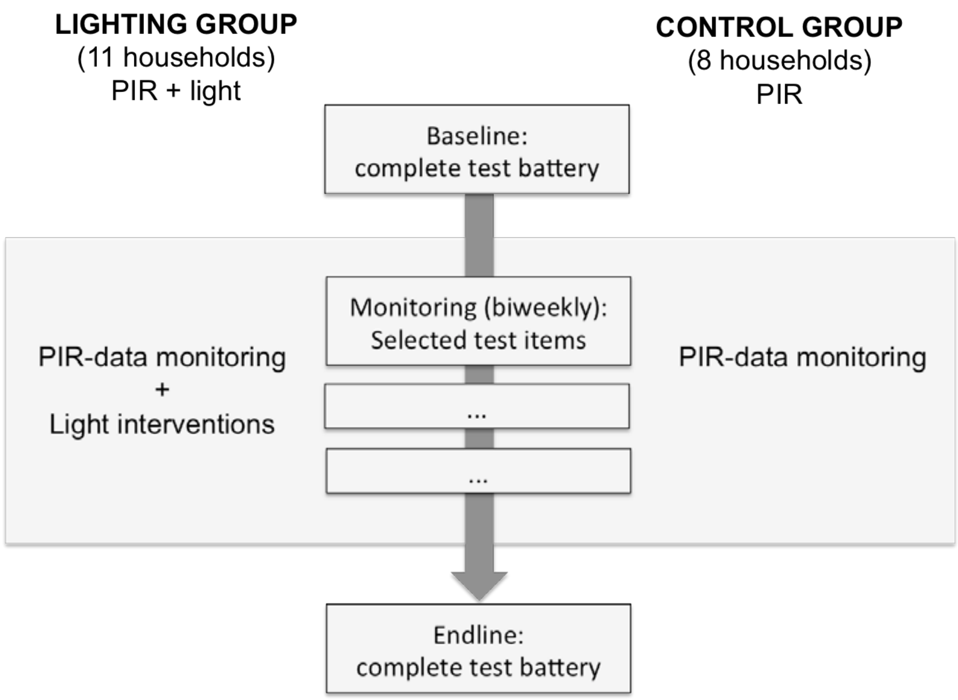

Figure3: Test plan of the field trials realized in the GuidingLight project.

The field trial design, together with the tests and information sheets, were approved by the ethical committee of the Ludwig-Maximilian-University Munich (Germany).

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[3] Recruiting process took quite long for most of the households. In addition, several technical obstacles (installing internet connections, delivering of hardware components) occured that had to be solved before light intervention and data collection could be successfully started. The starting dates for the light interventions and different measurements of each household are described in Annex II.

2.2. Definition of evaluation tools and metrics

Based on our extensive literature performed at the beginning of the project (see the results in D1.1), we supposed that the following variables could be optimized by our lighting intervention:

- General wellbeing, mood
- Drive for perform daily activities (physical & social)
- The performance of daily activities (personal care, cooking, reading, hobbies)
- Temporal orientation (in terms of daily structure)
- Spatial orientation (in terms of safer toileting at night, less falls)
- Day-night-rhythm / sleep
- Appetite / pleasure while eating

In order to measure these variables, a collection of psychological measures, scales and tests were researched and a selection of the most appropriate ones was chosen, which is presented in detail in section 2.2.1. Furthermore, the mobility profile of each person (based on the PIR data) was defined in terms of distinct mobility parameters (see section 2.2.2), which were analyzed for light effects, as well.

2.2.1 Psychological Parameters: Test Battery

The above listed choice of psychological effects was covered by several tests aiming to measure these variables. Since the baseline and endline measurement included 11 tests in total with varying duration and difficulty for the users, the test battery was split into 2-3 dates in order to keep the effort for the senior test persons at a reasonable level (max. 40 minutes/date). Furthermore, at least 1 day of break was planned in between test sessions.

Out of the complex test battery, about 15 questions were selected for a short online monitoring questionnaire to be answered every other week by all participants to monitor their rough conditions. The online monitoring was answered either via the test persons' own computer (with a saved link in their familiar browser), or participants were equipped with a tablet PC (iPad) sponsored by the project and given written step-by-step instructions, as well as personal guidance at the beginning how to use it. Participants were reminded to answer the monitoring questionnaire regularly.

In the endline measurement, the tests of the baseline measurement were repeated to test for the effect of the lighting interventions. For the light group, a questionnaire on the usability and acceptance of the lighting system (TSQ-WT: Telehealthcare Satisfication Questionnaire - Wearable Technology) was added. A selection of 5 items test was also added to the biweekly monitoring test (again, only for the intervention group).

In order to control for error influences by social contacts, the S-Net and X-Net were included into the measurement: In addition, participants could report any extraordinary events that might have influenced their mood or health, e.g. conflicts with children, health deteriorations (independent of the light) or joyful holidays.

Figure4 gives an example for the online-monitoring tool, and Table 1 shows the focus and items used for the different tests.

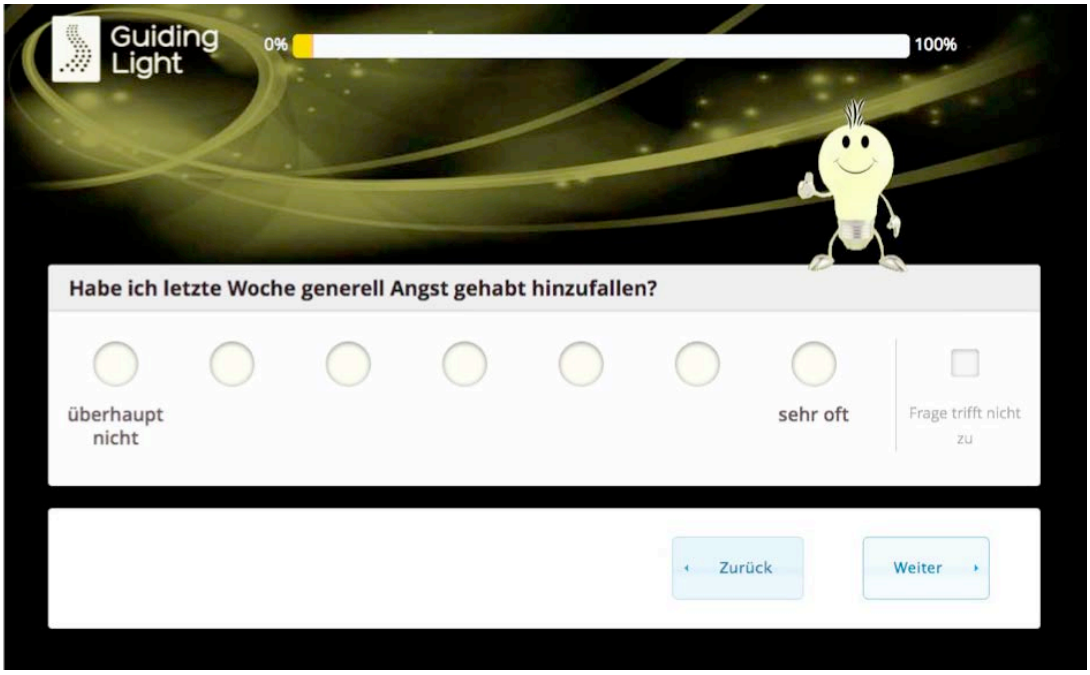


Figure4: Example display of the online monitoring test (asking about the fear of falling).

Table 1: Overview of tests and test items used for the evaluation for the effect of guiding light. Questions of the monitoring items always referred to the last week. Since test persons were all able to speak and understand German (Italian households were located in South Tirol), all tests were conducted in German.

Target Variable	Baseline test	Items of biweekly monitoring	Endline test
Health	HLTH	❧ How has your physical condition been? ❧ Have you feared to tumble?	HLTH
Eating / appetite	-	❧ How has your appetite for main meals been?	-
Visual performance	MARS	(none)	-
Sleeping quality	PSQI	❧ How fast have you fallen asleep? ❧ How often did you sleep through?	PSQI
Everyday life activites	IADL	❧ How often did you go shopping by yourself? ❧ Have you been a good walker (with or without walking aid)?	IADL
Spatial orientation	3DW	❧ How often did you get lost? ❧ How well did you find things in your	(3DW > discarded)

Target Variable	Baseline test	Items of biweekly monitoring	Endline test
		flat?	
Temporal orientation	Time estimation test	❧ How often were you pushed for time? ❧ How well did you estimate daytime?	Time estimation test
Drive	EWL-K	❧ How well were you able to motivate myself for daily activities? ❧ How often did you look forward to a new day?	EWL-K
Mood	EWL-K	❧ How did you feel? ❧ How often did you have a good time with other people?	EWL-K
Wellbeing	WHO5	❧ How many interesting days did you experience? ❧ How satisfied have you been with your current situation?	WHO5
Social Network	S-NET	❧ How many new people did you get to know? ❧ How often did you meet with friends or relatives?	S-NET
Reference person	X-NET	❧ How often did you have confidential communications? ❧ How many people were interested in your wellbeing?	X-NET
Usability (> light group)	-	❧ How did you experience the automatic light switching? ❧ Did you enjoy the use of the lighting system?	TSQ-WT
Acceptance (> light group)	-	❧ How did you like the lighting in your flat? ❧ Would you recommend the lighting system?	TSQ-WT

The online questionnaire was adapted several times to the needs of the senior test persons (e.g. asking only 1 question per screen, maximising button size). Most of the participants were capable of doing the monitoring questionnaire on their own. Some needed help by relatives or telephonic guidance by the examiners responsible for the household. In some single cases, the monitoring was done by telephonical inquiry of the examiners because test persons could not do it themselves.

In the course of the baseline tests, it became obvious that the 3DW test (showing a fantasy dice from different angles) was too difficult for the test persons: some tried hard to solve it (but barely succeeded with a single subtask), and the majority even refused to finish the test or even start trying it. In the absence of an appropriate alternative, the test was omitted and not included in the endline measurement, neither.

Due to holidays, times being sick, as well as trouble with the tablet or internet connections, the frequency of answering the monitoring showed some variance within the test group.

The time of applying the online questionnaire is described in annex IV.

2.2.2 Mobility Parameters: PIR Data

The analyses of the PIR-sensor data of the households, taking place every 14 days, comprised the evaluation of the activity during the day (amount of stays, degree of movement during the day, time spent outdoors), the daily structure (deviation of nominal stays, deviation from the beginning of the nominal stay, deviation from the end of the nominal stay) and the sleep quality (degree of movement during night, sleep duration during night, time spent awake during night).

At the beginning of the study, the individual daily structure of each participant was ascertained to get a picture of the usual daily routine. To know about the initial situation of each person is important, because this information can serve as a leverage point for “improvements” and changes over time can be recognized. The determination of the location are probability statements, which means, it is established how likely the probability of a stay or movement in a specific room zone is. For a selected time the likelihood of stay will exist for several room zones but will be highest for just one room zone, which then will be identified as the location of stay (see detailed description in chapter 4.1.1).

2.3. Participating households

The following sections will examine the details of the recruiting criteria (2.3.1), the recruiting process (2.3.2), and the recruited participants (2.3.3), i.e. the light intervention and the control group.

2.3.1 Recruiting Criteria

In general, the guiding light system has been developed to support elderly people in their homes. There is no specific age range or any other constraints as to the usage of such a system, since it turns on and off automatically (at least the ambient light) and the switches are identical to the ones normally used (apart from their cable-free installation).

For the field trials, however, more constraining aspects had to be taken into account: With regard to the financial budget, households for the field trial should not be too big in order to keep installation costs at a minimum (1-3 rooms). Furthermore, only one person should be living in the flat in order to be able to analyse mobility patterns of the inhabitant in the flat. This also included that the ownership of a pet (moving around in the flat) was to be avoided.

Regarding the ability to perform the regular tests and to give feedback regarding the lighting system, the cognitive abilities of the recruited persons should ideally be intact. In contrast, some mild problems with mobility, sleep or mood would have been appreciated (but were not mandatory) to be able to prove some light effects – which is more of a challenge with seniors who already feel absolutely well from the beginning of the field trials.

In general, the candidates needed to be willing to have their complete lighting in their flat exchanged, and to conduct the numerous planned tests and questionnaires. Ideally, the control group ought to be comparable to the light intervention group regarding test relevant variables like health condition or social aspects that might influence the results.

Table 2 gives an overview of the inclusion and exclusion criteria.

Table 2: Screener of GuidingLight test persons.

Domain	Inclusion criteria	Exclusion criteria
Demographics	> 65 years of age Living alone in a 1-2 room flat Living in Austria, Germany, Italy and Switzerland	Pet (moving around) High level of care
Cognition	Ability to agree to participate and to understand that termination is always possible Compliance/ability to participate in tests and answer questionnaires regularly	Dementia
Health	minor mobility, minor disturbances in circadian rhythm, minor disturbances in orientation	Severe health conditions or illnesses most probably leading to a deterioration within the duration of the field trials (e.g. cancer, heart diseases) Severe illnesses of the eyes Severe neurological or psychiatric conditions (clinical depression, addiction, epilepsia), intake of psychotropic drugs

2.3.2 Recruiting Process

The recruiting of test persons turned out to be a bigger challenge than we had thought at the beginning of the project: contacted retirement homes, real estate managers or local municipalities were often sceptical about having some of their inhabitants taking part, either because they feared the extra effort arising for staff members due to the project (which they wanted to avoid at all costs due to already heavy overload of employees), or because they were convinced that seniors would not want to participate.

Furthermore, single seniors compatible with all the screener defined variables were difficult to find in our partners' databases and even within consortium partners' friends and relatives:

many still lived together with their partners, some interested candidates suffered from dementia or other neurological diseases (like multiple sclerosis), had pets to alleviate their solitude if living alone, were “too mobile” to be included in the study, or the flats did not match our criteria (e.g. if living rooms were too big, flat was too far away from supervising partner to guarantee immediate support). In addition, some seniors had concerns about their lights being exchanged as they had often taken them from the (bigger) places they had lived before, together with their partners and children, and so they were important mementos to them from bygone days they did not want to miss.

The recruiting process started shortly after the beginning of the project (i.e. in autumn 2013) and was finished not before summer 2014, showing the strenuous effort it had taken us to find suitable participants. At this time, we had finally been successful and had found all the 19 persons willing to participate in our study, including test persons from the different countries represented in the project’s consortium (Austria, Germany, Italy, Switzerland). (The participants are described in more detail in 2.3.3 and in Annex II.)

Unfortunately, one participant had to be exchanged during field trials (test person “VP06”) because the original senior moved from his residential care home into a care facility due to deteriorated health status.

The process from recruiting the participants till the new lights had been installed for the light intervention group is shown in Figure 5. The process was similar for the control group, except for the light installation.

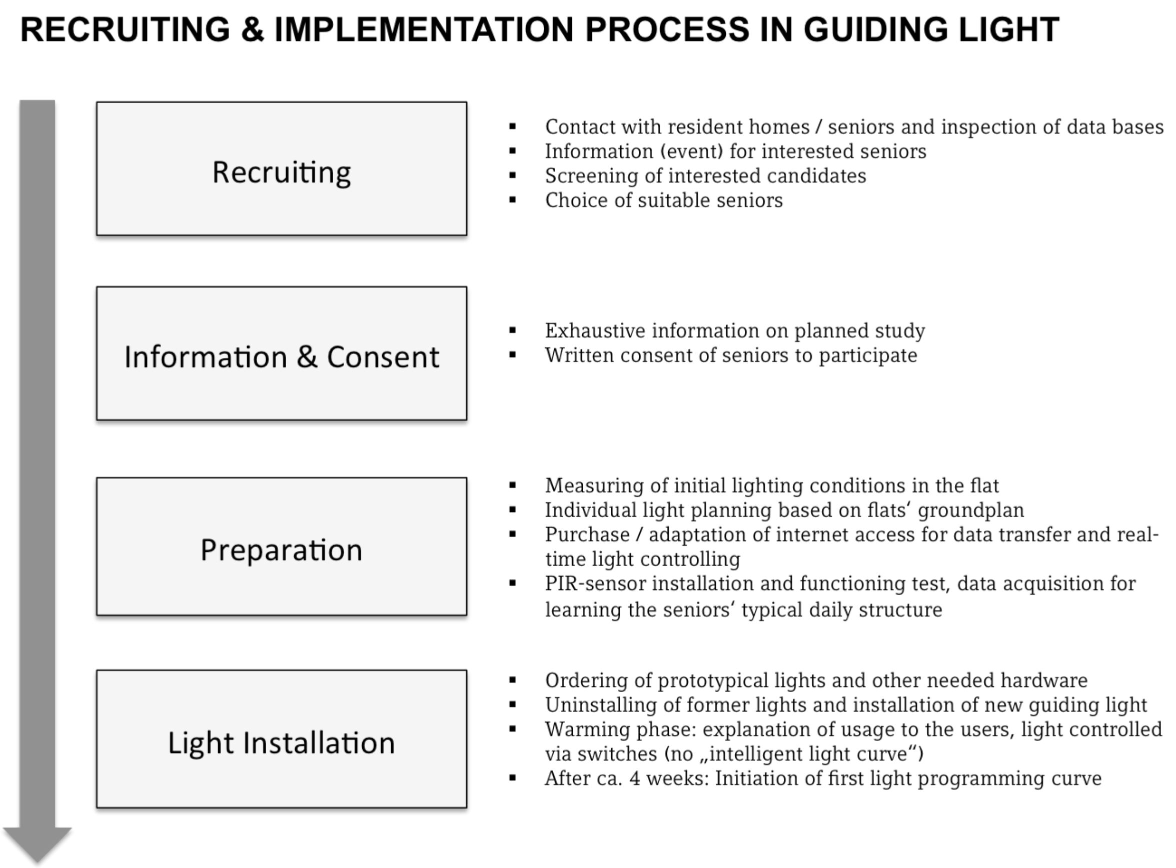


Figure 5: Process of recruiting participants and preparing the starting of the field trials in the GuidingLight project.

For the recruiting, a short presentation about the background and aim of the GuidingLight projects was prepared, together with information sheets to arouse the interest of suitable candidates. Interested seniors were shortly interviewed to test for the screener variables. If candidates were suitable for participation, they were given a detailed information brochure (containing information about privacy) that was discussed with them until all open questions had been answered. After giving them time to rethink about it, participants gave their written consent, and the preparation for the field trials began.

First, the ground plan and the initial lighting conditions were compiled as a basis for the individual light planning done by the partner Bartenbach (for details see D.3.2.). Light positioning and light type were defined for each flat so that the illumination corresponded to the formerly researched recommendations for elderly persons' homes.

Furthermore, the positioning of the PIR sensors had to be planned invididually so that single areas in the flat could be identified that are aligned to distinct activities (cooking, eating, reading, changing clothes etc.). Thus, the patterns of daily activitites could roughly be derived from the movement activities recorded by the PIR sensors. Sensors were installed (with special adhesive tape) at the ceilings before the installation of the light, so that the algorithm of detecting the daily movement patterns could be trained for every inhabitant. The white cover rings, that had been used for aesthetic reasons, had to be removed from the PIR sensors in some flats because some of them were falling down due to the heavy weight in combination with the undercoat of the wall. Luckily, nothing bad happened and no one was hurt. After removing the covers, the sensors kept sticking to the ceiling without any further problems.

In addition, a mighty Internet access was needed with a fix IP address, so that the lighting could be controlled via gateway/controller based on different light curves saved on a server and adapted repeatedly. The Internet connection also ensured that the participants could answer the regular monitoring questionnaire. If Internet access was already available, it was made sure that a fix IP could be added on. For households without Internet access, a new connection had to be ordered and installed, a process that sometimes took several months. Furthermore we had to learn that the regulations of internet connections differ from country to country: for instance, in Germany and Italy, IP addresses are constantly changed and distributed newly every night for regular contracts. Thus, special contracts (for companies) had to be signed for the private test persons (producing extra costs and efforts).

MyVitali had provided an app that allowed the examiner to test the functioning of the PIR sensors (and the lights) with a smartphone quite easily (even remotely), which was very useful not only for the initiating of the system, but also for trouble shooting necessary throughout the progress of the field trials.

Once planning had been finished and coordinated with the inhabitants, the material was ordered (PIR sensors, different types of lights, controller, gateway). Delivery times were about 6 weeks. As soon as the material had been sent, a date had to be fixed with a local electrician, the examiner, and the test person. At this date, the old lighting system was removed and the new one was installed, which took the electricians about 2-3 days until everything was finished. The installation time was often very exhausting and stressful to the participants, because of the noise and dirt, but also due to the agitation arising from many people being present in the flat during the day and the disruptions of normal personal habits. In addition, some seniors were not so happy about the design of the new lights or the surface-mounted cabling that was used in most cases so that the lighting system could be removed after the field trials with less effort if the participants did not want to keep the lighting afterwards.

Figure 6 shows scenes from the installation process – more details can be found in the implementation report D3.2.

Figure 6: Snapshots from the installation process in one of the test flats of the intervention group. Left: Downlight – Right: pendant light.

2.3.3 Recruited Participants

To measure the effect of Guiding Light, the LED-lamps with the day-/night rhythm control and the daily structure rhythm control were tested over a period of half a year, from summer 2014 until Spring 2015, in a few private households. Four households were equipped with the daily structure rhythm control and seven households with the day-/night rhythm control. For reasons of control and to measure the extent of possible light effects, eight test households without a Guiding Light system were included in the study.

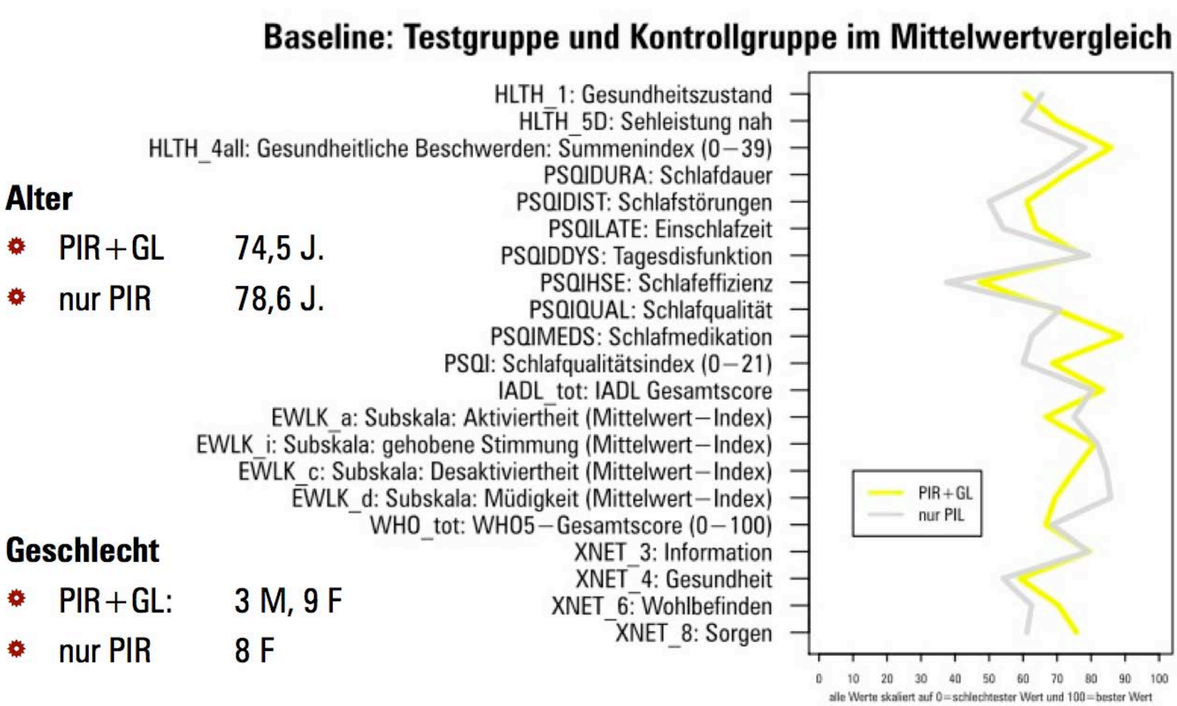
The subjects were living alone men and women in the age of 63 to 89. At the beginning of the study they didn´t differ substantially regarding their physical fitness (e.g. fear to fall), their mental fitness (e.g. spatiotemporal orientation), their extent of social contacts and their quality of sleep and life.The original average illumination of the 19 test households was Eh = 30 –

1500 lux in the living space and the kitchen, Eh = 70- 250 lux in the bathroom and Eh = 40 – 150 lux in the bedroom.

You will find a detailed description of the test persons in Annex II.

Table 3: Overview test persons GuidingLight

	Experimental group (n=x)	Control Group (n=y)
Gender	Women/men: 9/3	Women/men: 8/0
Age	Range: 65 – 86 years Mean: 74.5 years	Range: 65 – 86 years Mean: 78.6 years
Walking	With mobility aid: 2 Without mobility aid: 10	With mobility aid: 1 Without mobility aid: 7
Flat	Mean: 45.3 square-meter 2-room: 7 3-room: 5 high standard	Mean: 48.1 square-meter 2-room: 2 3-room: 6 high standard



3. Realisation of Field Trials

3.1. Implementation of lighting system

For the implementation of the current development status of a total "Guiding Light" system, a deep cooperation of the following partners was done:

- BB: lighting design, order and quality assurance of luminaires, compilation of a comprehensive installation handbook for work on site
- MVA: cloud configuration, order, teaching (techn.) and quality assurance of EnOcean components, telemaintenance for test persons, electricians and local (technical) contact persons
- FHV: implementation of webbased mobility monitoring tool including mobility assessment (parameters) and intelligent control algorithms, and the light curve editor
- On site: qualified electrician and supervision person from the local consortium partner

For the (first) implementation of the wireless solution (test persons 1, 2, 3, 4, 7, and 8) mobile Internet accesses were installed (in the period March 2014 to May 2014). During initial operation of remote light programming (i.e. readjusting dim levels via remote control) it turned out that mobile internet provider are not able to offer sufficient and / or stable port forwarding (including a fixed IP address), which is essential in the system architecture. Therefore starting with May 2014 all test apartments were changed to cable based internet providers. This solved the problem of port forwarding, i.e. unlimited remote access was achieved.

The positioning of the PIR sensors was jointly done during planning phase. Out of the experience of the implementation a fine positioning and detection validation had to be done directly during installation on site. This was done by the person who was installing and at the same time testing detection range, detection sensitivity, etc. in real time with the software visualization (e.g. on a tablet PC). The PIR sensors are used for motion detection and brightness measurement in the test apartments. There were mounted between five and seven sensors per apartment on the ceiling. With that the system can detect entering into a space-zone or leaving a zone. An additional sensor has been installed at the entrance doors of the test apartments, which detects the opening and closing of that door. During September 2014 there was taken a closer look at the raw data, especially the movement data, checked for plausibility and compared with the activity monitoring. Out of this raw data it can be seen that the movements are very well recognized. Activities with little movement expenses, such as reading, writing or head movements were not detected or only in the immediate vicinity of the sensor.

Following the conclusions of the PIR sensor validation:

- In combined living rooms-kitchens, it is difficult to divide the stay in residential area and kitchen area.
- The monitoring tool has improved (since start), but still some problems occur (state September 2014):
  1. As soon as more than one person is inside the flat mobility monitoring may have problems. This is difficult to fix and may need to be accepted as a source of error.

2. There exists a predefined lower limit of the duration of outdoor stays in order to be displayed as such one.
3. Stay in the sleeping area is not documented, but only the sleep time. This leads to the fact that when the test person wakes up, goes to the bathroom for 15 minutes and then back into the bedroom, the system assumes that the person sleeps for another 15 minutes, which is very unlikely. The total sleep time could thus be easily falsified. Also in the range of motion, which is calculated based on change of presence, this increases the inaccuracy.

- The measured illuminance levels from the PIR sensors are indeed imprecise and vary partly strong, but tend to agree with the luxmeter.
- The door contact of VP7 working poor.
- The detailed analysis of the raw data of the sensor validation gave good plausibility (no hardware problems in the PIR sensor) => as described above, further improvements in the monitoring tool (i.e. In the software logic) are under work.

Remark: improvement of the software logic is a continuing process and aim until the end of the field study evaluation.

If approved by the test person (e.g. due to aesthetical issues) within separate sleeping rooms the modified suspended luminaire was mounted and showed a good performance by having at the same time a lower installation effort. Therefore this version of lighting design for sleeping rooms is recommended.

Example. Test person 8 had moved into this apartment with August 2013, i.e. only a cooker lamp and a bathroom luminaire were installed. Test person 8 had some moveable floor lamps which were moved and adjusted every day (also between rooms or rather room zones). The initial lighting situation of apartment of test person 8 was very poor (except the bathroom which was illuminated adequate, measurements are in [D3.2]). The Guiding Light hardware installation (ambient light up to 300lx and zonally task light up to 2000lx) was finalized on 20.03.2014 in this flat.

Figure 7: The kitchen of test person 8 before the installation of GuidingLight.

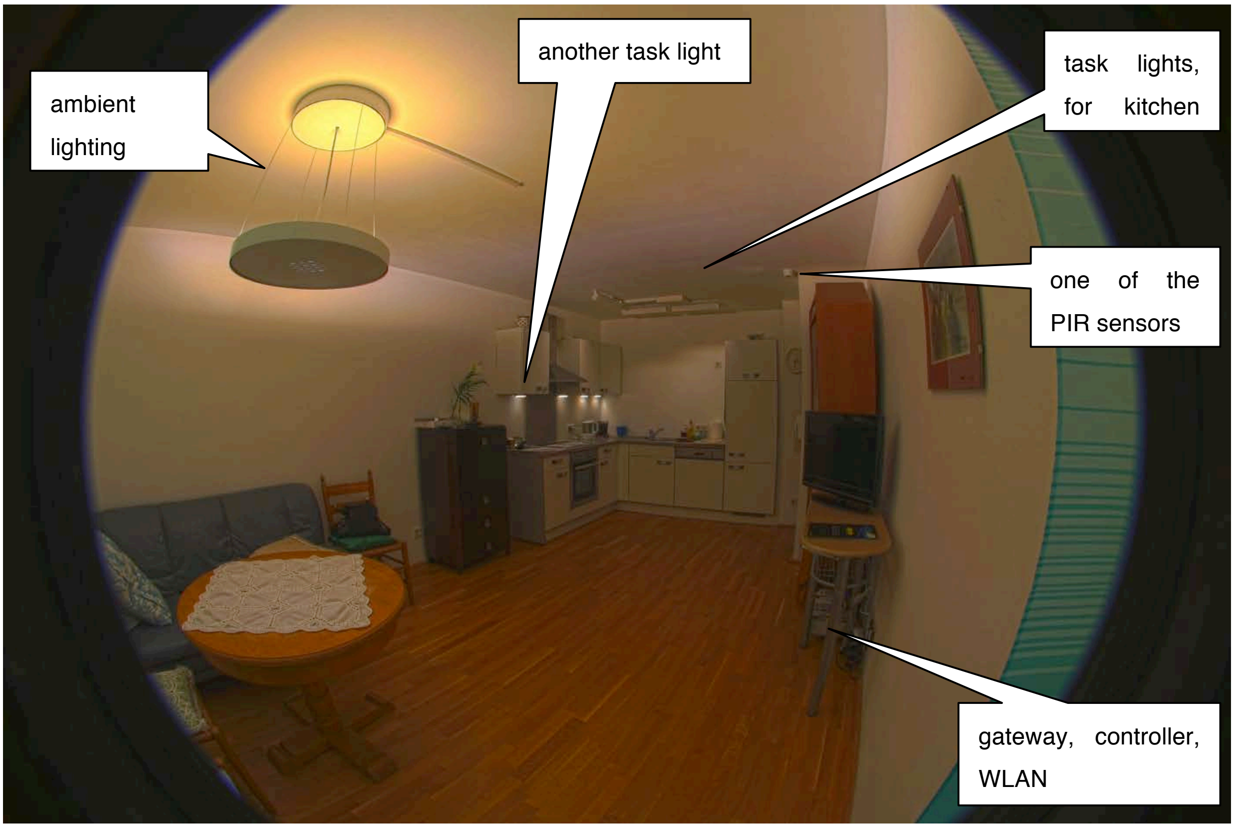


Figure 8: The kitchen of test person 8 after the installation of GuidingLight.

Within this apartment, it was possible for the first time (and approved by the test person) to realize exactly all details of the lighting design guidelines [D3.1]. From special interest is the ("modified", i.e. without direct component) suspended luminaire for the sleeping room illumination.

Basically, the installation of the Guiding Light system should make full use of pre-existing power outlets and avoid the installation of new cable channels for additional power outlets on the ceiling and walls.

3.2 The Light

Every apartment was designed individually according to its specific size and furnishing in order to meet all age-specific lighting requirements (see table below).

The following table shows an overview of the lighting requirements based on the scientific findings [see also D1.1], market survey (concepts, incl. luminaires and components) and long lasting experience of Bartenbach in the definition of lighting requirements and lighting design.

Time	CCT		(horizontal) illuminance	
	Ambient	***Task***	***Ambient***	***Task***
Day	4000K		300lx	1000lx (up to 2000lx)
Evening	2200K		150lx	300lx (up to 1000lx)
Night			< 50lx	< 300lx

Glare specifications:
- Task light: without any glare
- Ambient light: L < 1000 cd/m²

Brightening (wall and ceiling illuminance)
- during day: 150lx
- during night: 75lx

Figure 9: LIghting requirements according to special needs of elderly people, according to our findings from T1.1.

The lighting design consists of separate ambient- and task light (controlled separately, multitude of lighting scenarios, adapted to use cases).

Based on the daily structure of the test persons, a detailed adjustment of illuminance level and CCT for different day times and room zones takes place. These (realized) requirements are much higher as current status quo in general private homes (usually values of artificial illuminance are below 100lx; reference [D3.2] and predecessor project "aladin"). Special attention were focused onto the increased glare sensitivity by elderly (this is a technical feature which had to be considered already during development and / or implementation of optical components into the luminaires). In order to realize a biological effect the lighting design paid attention to a well-balanced ambient brightening (realized by correct vertical illuminance levels).

The developed lighting design guidelines [see also D3.1] are valid for standard apartments with five typical spatial zones (entrance area, living room, kitchen area, bathroom and bedroom) and a size of 30 to 55 m² (approx. 2 to 3 rooms). The goal of the guidelines is that a skilled electricians is able to design, install and maintain the Guiding Light system.

These lighting requirements were programmed with the web based tool "Light curve editor". Bartenbach and FHV followed two slightly different approaches:

3.2.1 Approach I – daily structure light intervention

For the light programming we distinguished between ambient room lighting or homogeneous illumination of a room and focused illumination of particular room zones. Ambient room lighting is switched on and off presence controlled through the application of PIR-sensors (Passive-Infrared-Sensors). Just in the bedroom the light has to be switched on and off manually.

The automatic registration of a persons attendance in the other rooms is not only based on a locally recognition of movement but also through an analysis of the suite of releases of all PIR-sensors in the household and a thereof deduced conclusion where a person is located. If there is more than one person in a room, the light turns off within a predefined follow-up time after the last person left the room. Unlike the room lighting, the room zone illumination has to be switched on and off manually.

The basic setting of light intensity and light colour of the ambient room lighting are defined as follows (see Figure 10 top): The light is constantly at 300 lux and 400 kelvin from the individually planned get up time till two hours before bed time. Two hours before the planned bedtime until the actual bedtime the settings are at constant light at 150 lux and 2200 kelvin – this corresponds with the evening illumination. The time between bedtime and the planned get up time the illumination is at 50 lux and 2200 kelvin – this corresponds with the night illumination. The brightness levels are applied for ground level. The transition between the different ambient lighting moods takes place within half an hour by linear interpolation.

The basic setting of light intensity and light colour of the room zone lighting is determined by two selectable control logics (approaches I and II). The approach I is for the illumination according to the daily structure rhythm. The basic setting for this logic initially follows the approach II. Additionally this logic is combined with the individual daily structure (see Figure 10 below). When the light sensor is actuated, the luminaires of a room zone are only activated with the maximum brightness, if a person should stay in this particular room zone according to her individual daily structure. Otherwise, the room zone lighting uses the adjustments of the ambient room lighting. The transition between the different zonal lighting moods in both cases takes place within half an hour by linear interpolation. The light control curve of the illumination with daily structure rhythm shows a linear interpolation course – from the brightness value of the ambient room lighting to the brightness value of the intended active room zone lighting.

The approach I gradually adapts the light attributes based on continuous feedback of the light effects on human beings. In this case, the light control is considered as an evolutionary system. During a continuous, but barely perceptible, change of the light attributes, only those attributes are continued which achieved the desired effects. This illumination complies with the daily structure rhythm. For the subjects under this condition every 14 days (+/- four days) all luminaires were automatically reprogrammed by means of a rule based system based on an analysis of continuous measured PIR-sensor data (see D3.2).

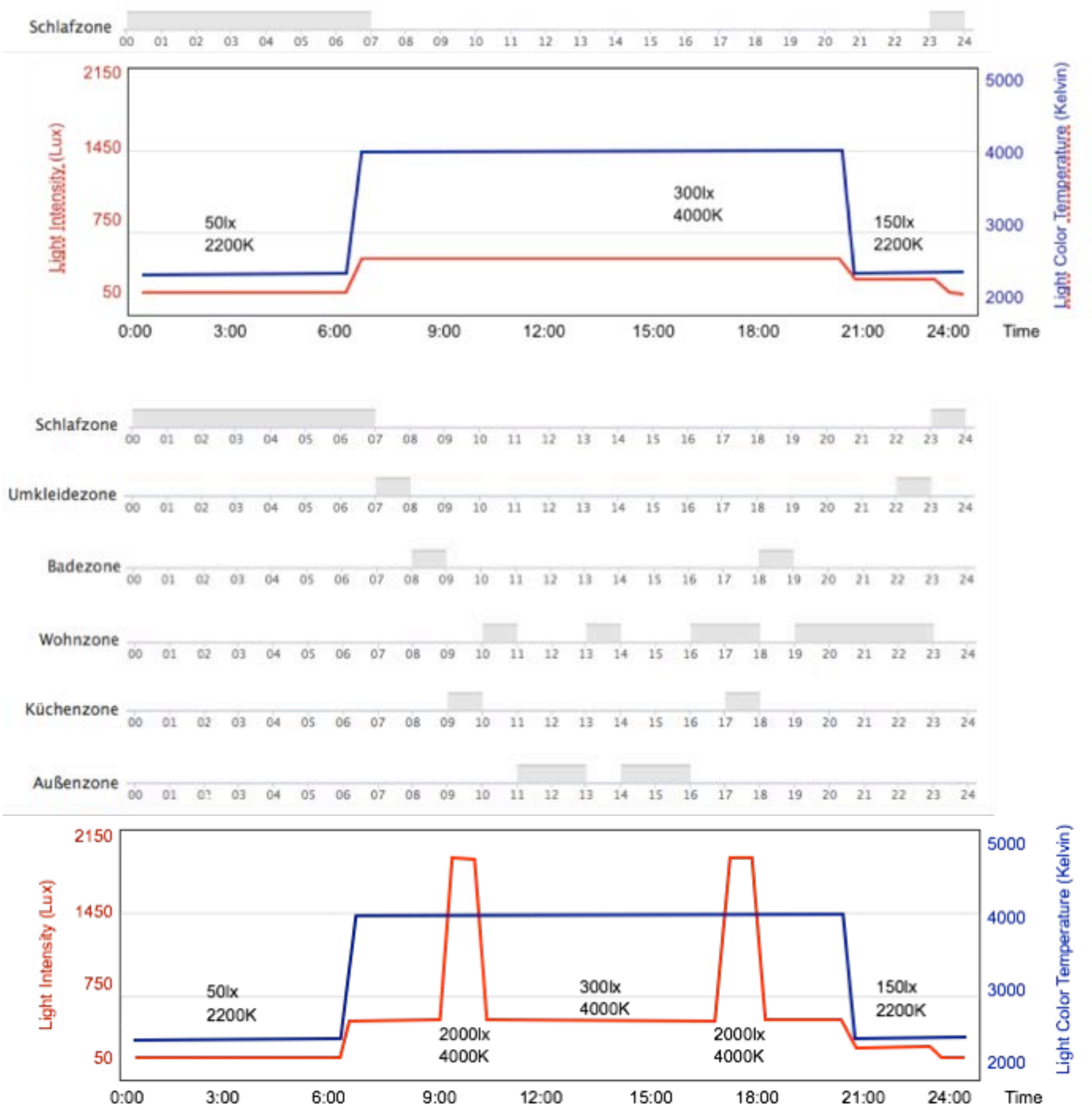


Figure 10: Exemplary light control curve with daily structure light intervention (basic configuration). Top: ambient lighting for all rooms. Bottom: daily structure light intervention for kitchen zone.

The aim of the on going optimization process of the daily structure rhythm was, based on the above described basic setting, to modify the maximum brightness of the ambient room lighting, the maximum brightness of the active room zone lighting, the division factor of the evening ambient room lighting, the division factor of the nocturnal ambient room lighting, the division factor of the evening active room zone lighting and the division factor of the nocturnal active room zone lighting, if necessary. Following alteration constants were used for the adjustment vector: for the maximum brightness a 5% alteration constant, for the division factors of the evening and nocturnal room zone lighting a 20% alteration constant and for the division factor of the evening and nocturnal room lighting a 10% alteration constant. The brightness of the inactive room zone lighting followed the brightness of the ambient room lighting.

The analyses of the PIR-sensor data of the households, taking place every 14 days, comprised the evaluation of the activity during the day (amount of stays, degree of movement during the day, time spent outdoors), the daily structure (deviation of nominal stays, deviation from the beginning of the nominal stay, deviation from the end of the nominal stay) and the sleep quality (degree of movement during night, sleep duration during night, time spent awake during night).

The deduction of a changing vector for the new light programming was based on the comparison of the last two every 14 days measuring periods. If the new programming lead to an optimization of the parameters the pursuant control variables weren´t changed. If deterioration occurred, the system repeated the last change of the control variables, which achieved an improvement. If that change also didn´t show an improvement, the opposite change of the last control variables was performed. If there wasn´t any improvement yet, the system cancelled the last change (just in the amount of the changing constant). In the case the new programming lead to a brighter light during the night than in the evening, the brightness of the evening light was chosen for the light during the night.

For the daily structure rhythm intervention the relationship between the light control values and the valuation parameters was determined in an effect matrix. The rule-bound system accessed this matrix (see D3.2). If the daily activity decreased, the brightness of the ambient room lighting during the day and in the evening was changed. The brightness of the active room zone lighting by day and in the evening was changed, if the daily structure got worse. If the sleep quality decreased the brightness of the ambient room lighting during the night and the active room zone lighting during the night were changed in accordance with the optimization algorithm.

3.2.2 Approach II - day/night light intervention

The basic setting of light intensity and light colour of the ambient room lighting are defined in the same way as in approach I (see Figure 13 top): The light is constantly at 300 lux and 400 kelvin from the individually planned get up time till two hours before bed time. Two hours before the planned bedtime until the actual bedtime the settings are at constant light at 150 lux and 2200 kelvin – this corresponds with the evening illumination. The time between bedtime and the planned get up time the illumination is at 50 lux and 2200 kelvin – this corresponds with the night illumination. The brightness levels are applied for ground level. The transition between the different ambient lighting moods takes place within half an hour by linear interpolation.

The further logic for the illumination with day-/night rhythm is as follows (see Figure 13 middle): The light colour is the same as for the ambient room lighting. The maximum brightness is the result of a contrast sensitivity test, which determines the maximum brightness at any loss of visual performance (up to 2000 lux). From the planned get up time till two hours before bedtime the zonal illumination is at constant light and the determined maximum brightness. Two hours before the planned bedtime until the actual bedtime the zonal illumination is at constant light and at one third of the maximum brightness. The time between bedtime and the planned get up time the zonal illumination is at constant light and at one sixth of the maximum brightness.

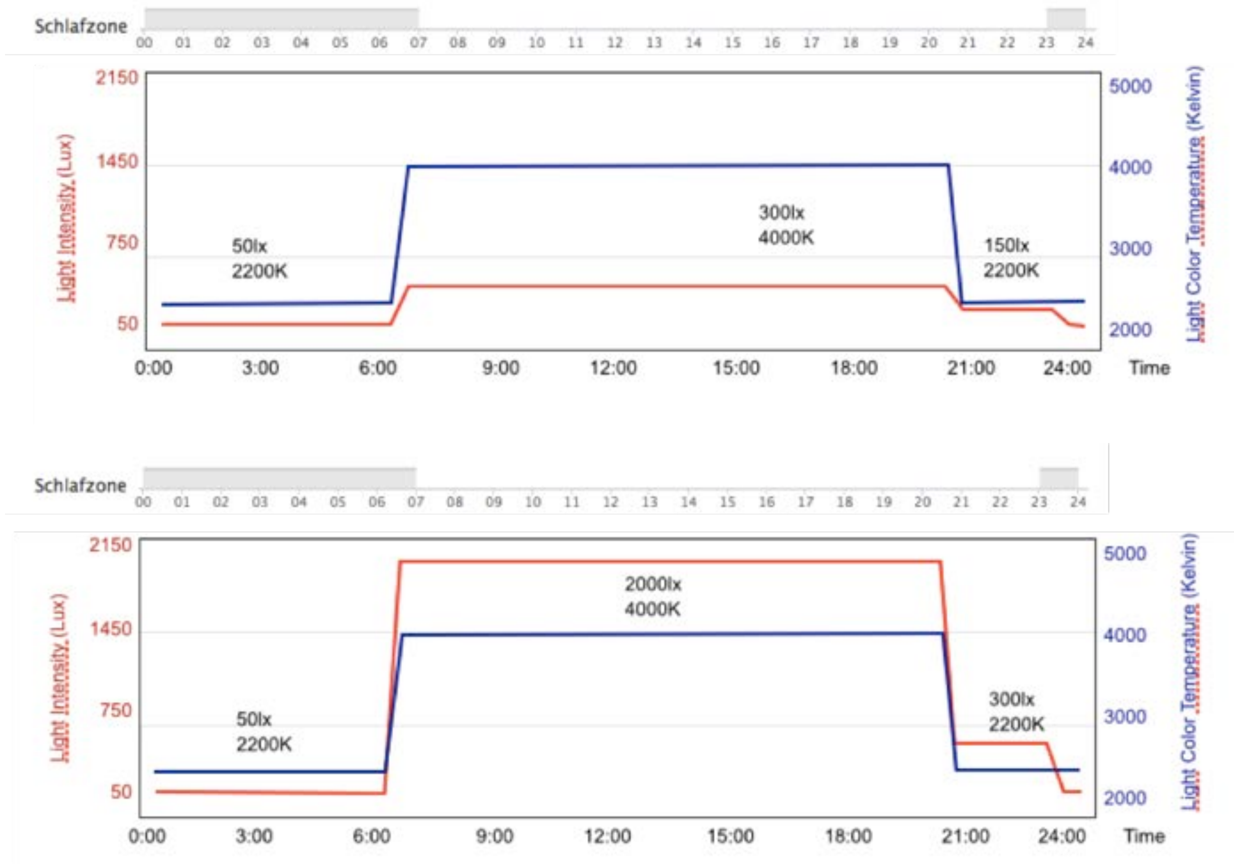


Figure 11: Exemplary light control curve with day/night light intervention (basic configuration). Top: ambient lighting for all rooms. Bottom: day/night light intervention for all room zones.

Because findings concerning the effect of single light attributes are divergent, two attempts were carried out to optimize attributes of residential lighting within the framework of Guiding Light. The first approach is based on the simulation of a sunset by means of room lighting, because this should have a positive impact on sleep quality and cognitive performance by day. This illumination complies with the day-/night rhythm. For the subjects under this condition every 14 days (+/- four days) the timeframe of the evening illumination was varied between two and four hours or directly switched between day and night illumination for reasons of control.

The approach II was realized in the test apartments of test person 1 - 4 (Youse), 7 and 8 (BB) and test person 10 (Apollis). Since 11.6.14 test light programming already in progress at VP7 + VP8.

This approach varies (mainly) the times for the "sleep cycle" and the light intensities for day, evening and night hours. There is no or little conceptual difference between ambient lighting and task lighting. With this approach the following hypothesis should be validated:

- **Temporal Mobility:** The intelligent lighting system, with daylight-controlled dimming of light intensity and CCT, stabilize the circadian rhythm. In particular, improved sleep patterns and sleep quality is expected (less sleep interruptions). The measured variables are sleep time, wake time, sleep interruptions.
- **Spatial mobility:** Further results from the stabilized circadian rhythm an increased activity and movement during the day. This improvement is to be measured by the defined mobility parameters.
- **Visual conditions** (intensity, uniformity, shading) are enhanced and falls are avoided. Subjective well-being is enhanced.

4. Results of Field Trials

The analysis of the collected data aimed at finding an answer to the following questions:

Is there a **positive effect of Guiding Light** on

- mobility
- daily structure
- activity and sleep quality
- visual performance of daily activities
- mood/drive

of the intervention group, compared to the control group?

Chapter 4.1 will provide the answers to these questions, separately for the two different lighting approaches. In chapter 4.2, the iterative enhancements of the lighting system are explained in detail, and chapter 4.3 focuses on the improvements of the user interface.

4.1 Effects of lighting on users

Empirical findings are rare, how the spatiotemporal variation of light intensity and light colour affects where a person stays at particular daytimes preferably. Guiding the places of stay in the flat, which can be influenced by room lighting, over the whole day and influence the time spent outdoors is the aim this project.

Guiding Light should lead elderly at determined times to predefined locations in the house, without any other external influence. One precondition is the assumption that room lighting increases not only the motility in terms of more physical activity but also the mobility in terms of effortless changes of the locations. Those effects, however, shouldn´t lead to undesirable actions, for example the “restless-leg-syndrome” or the “restless wandering” of people with dementia. The aim of Guiding Light is to fit increasing motility and mobility with a desired daily structure – to have “the right amount of activity at the right time at the right place”.

4.1.1 Results of Approach I: influence on mobility

Within the framework of Guiding Light motion detection and presence detection were carried out by PIR-sensors. Motion detection takes place through temperature change on the surface of the sensors. Temperature change can be caused through persons or other creatures which radiate warmth that come across the sensors, particular extensive body movements and other phenomena like warm drafts. The detection behaviour of the PIR-sensors is configurable.

Independent of the brightness in the room the PIR-sensor instantly sends the raw value “true” or “1” if there is any movement. If the sensor doesn´t register any movement for one second, he sends the raw value “false” or “0”.

In one room zone there can be one or more PIR-sensors. As soon as at least one sensor of a room zone registers a movement within one minute the minute meter is set to “true” or “1”. The minute meter for the time spent outdoors is set to “true” or “1” if for this minute the absence from home of the person is registered (see location determination). The degree of movement is calculated by the sum of the minute meters, e.g. for five room zones the maximum of movement in one minute can be five minutes, in case a person comes across all room zones in one minute. If the degree of movement of several days should be observed, the arithmetic mean of all minute meters of the same time of day is calculated.

For all participants of the control group (CG), the day-/night rhythm illumination group (DN) and the daily structure rhythm illumination group (DS) the average degree of movement per day was calculated. Then each group mean of the period before the first light intervention was compared with the group mean of the period after the first intervention. The two periods were depending on the implementation of Guiding Light and thus not the same for all participants. For the CG the process data were divided in two comparable time periods. Univariate ANOVA showed significant differences for the comparison of the degree of movement of different periods ($p < .001$). The degree of movement in the DS group increases from M_{DS1} = 683 minutes of movement to M_{DS2} = 789 minutes of movement whereas the other groups don´t show a significant increase (from M_{CG1} = 352 to M_{CG2} = 368 and from M_{TN1} = 252 to M_{TN2} = 253 minute of movement).

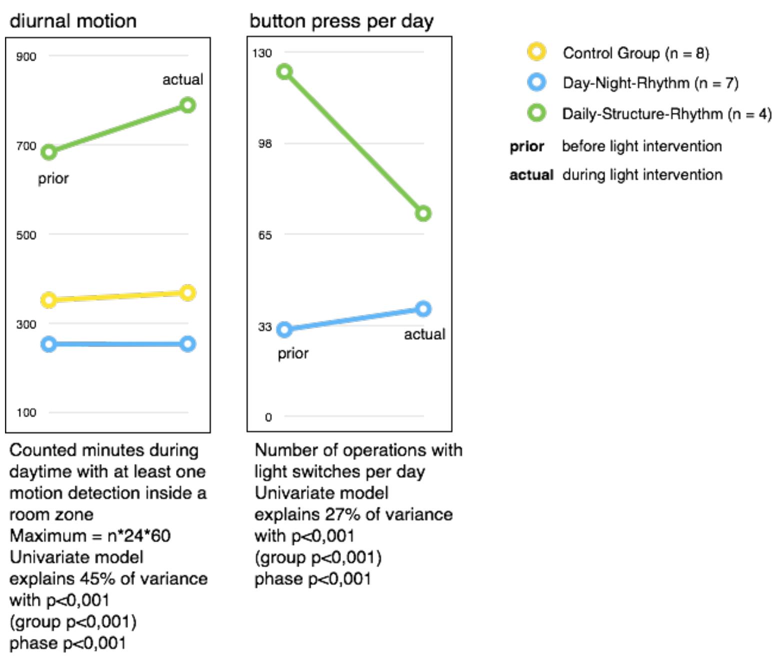


Figure 12: Influence of light intervention on motility.

Figure 13 shows the daily degree of movement of each group for comparable measurement periods. In the process data, a baseline around 250 to 350 minutes of movement can be recognized, around which the data of the CG group (tan α = 0.026) and the data of the DN group (tan α = -0.046) are moving. The light intervention doesn´t seem to have any impact in the DN group. Whereas in the DS group the baseline is just recognizable when a new participant joined the sample (for participant number 5 the first light intervention started before the displayed time frame). After the light intervention the degree of movement increases (tan α = 0.859) and reaches twice the extent of the baseline.

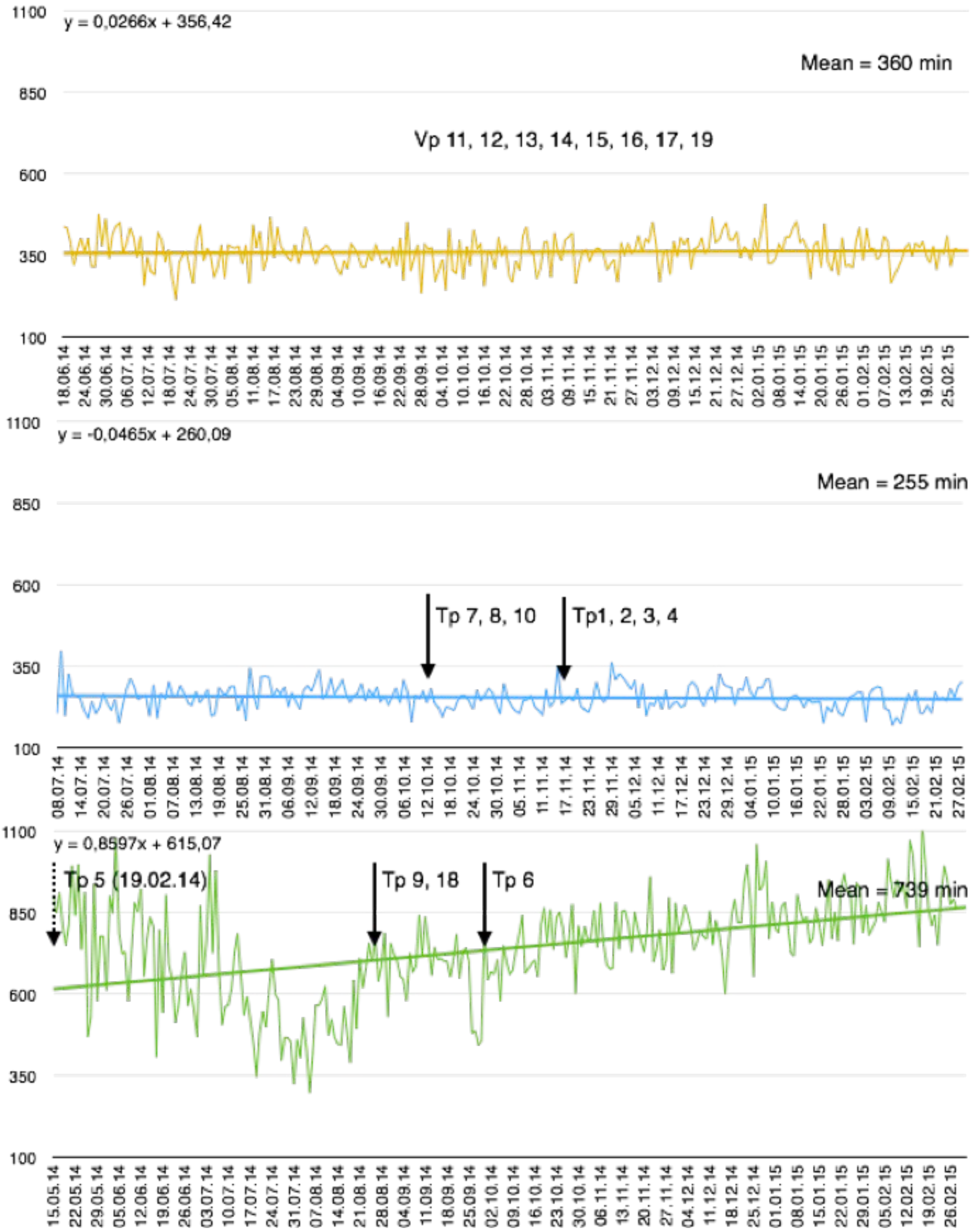


Figure 13: Number of minutes per day with at least one motion detection within the room zones, averaged for all persons of one group. Top: control group. Middle: lighting with day/night-rhythm. Bottom: lighting with daily structure rhythm. Arrows: start of light intervention for resp. test person.

The determination of the location of a person inside the flat is established based on the degree of movement. A stay in a particular room zone is assumed for that zone where the highest degree of movement at a specific time of day, one day or the average over several days was measured. The location of a person is calculated every half hour, which means that starting at 00:00 am every half hour it is determined in which room zone the degree of movement is highest and therefore assumed, that the person is located in that zone. One problem is that a person can stay in a room zone without any movement (e.g. while she´s sleeping). The PIR-sensors just recognize changes in temperature and therefore the determination of location with this evaluation logic can´t be done correctly all the time.

To minimize the error rate of the determination of location the degree of movement across all room zones and the zone outside the flat is compared on a daily basis. Because of the problem with the PIR-technic described above it can happen that all the minute meters show the value "false" or "0", which means no movement or stay outdoors is registered for that time. In this case that minute meter is set to "true" or "1" which showed the last "true" or "1". This is continued (and interpreted as a stay) until another minute meter is set to "true" or "1" after the registration of a movement.

The determination of the time spent outdoors follows an evaluation logic which assumes an absence if there´s no movement in the flat for a predefined time (e.g. 10 minutes) after a movement in the entrance area. In doing so, the registration of an absence during sleeping time can be avoided, because the last movement was in the bedroom, not the entrance area. Vice versa, the registration of a movement in the monitored area leads to a switch to "presence". It is configurable how many releases are necessary for this because sometimes PIR-sensors make wrong releases.

Figure 14 shows the average degree of movement over a month of one person (October 2013, February 2014, February 2015) in four room zones (sleeping zone, bathing zone, living zone and kitchen zone), the zone outside the flat (time spent outdoors in minutes) and the summed up degree of movement across all zones (cumulative frequency polygon) from 0 am till 12 pm every half an hour. The coloured bars display the stays of the person determined by the described evaluation logic.

At the beginning of data collection (October 2013) the person doesn´t have a fragmented daily structure – she just shows seven room zone stays and one stay outside. Especially the stay from 13pm until 23pm in the living zone is noticeable. Immediately after the first light intervention in February 2014, the person already shows ten room zone stays and two stays outside. After one year of light intervention, in February 2015, the person has 12 room zone stays and three stays outside. Such an increase isn´t expected usually for elderly people.

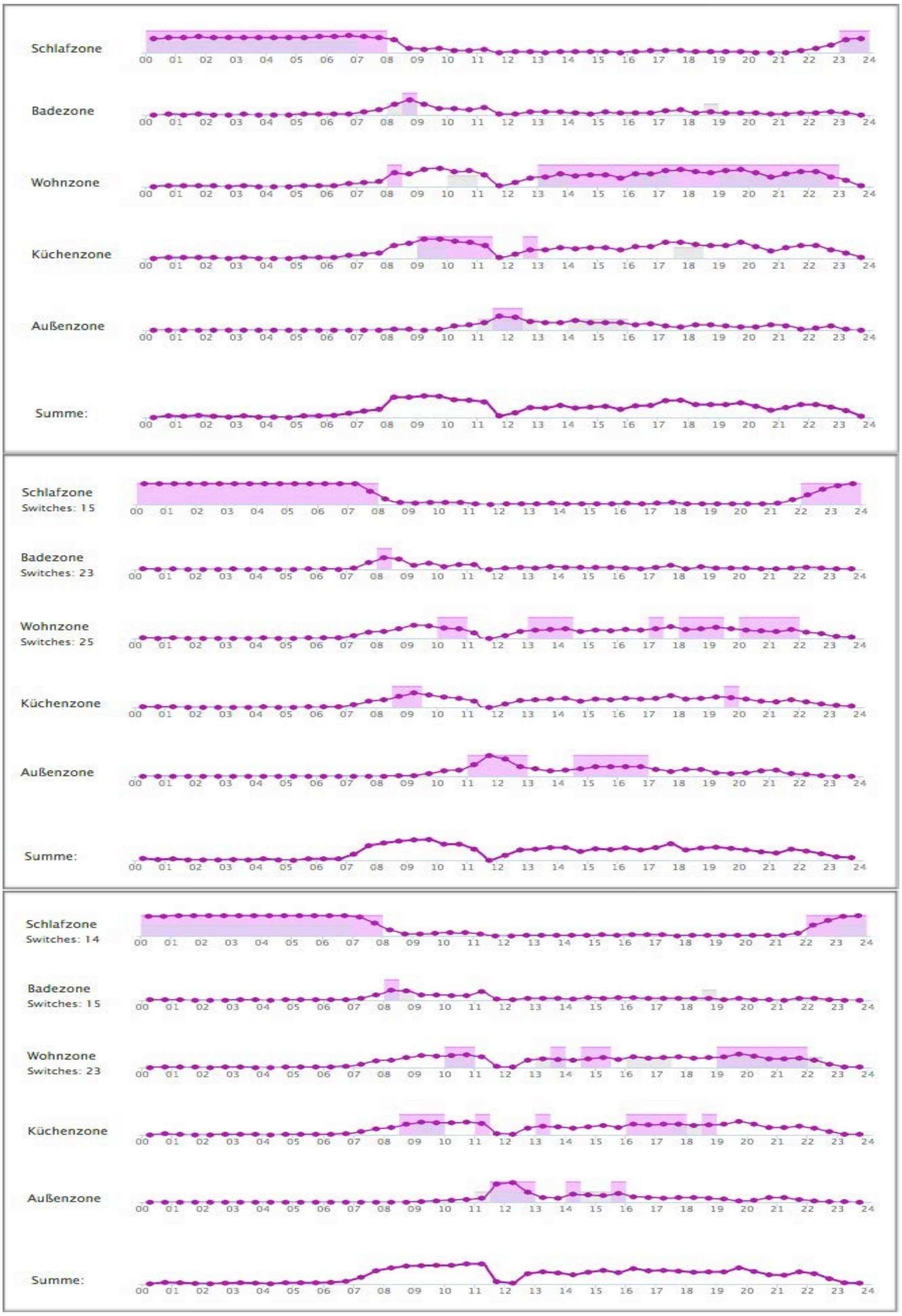
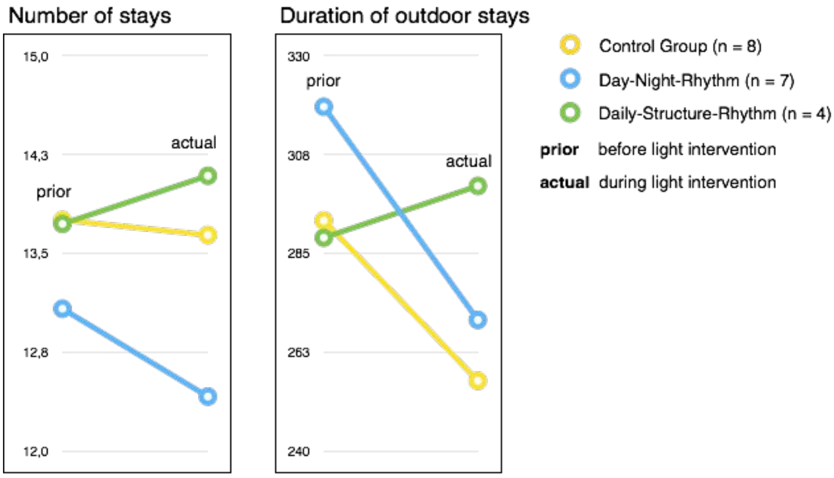


Figure 14: Daily structure of a single test person with daily structure light intervention identified for selected months. Highlighted areas mark the stays of this persons. Top: October 2013 (7 room zone stays, 1 outdoor stay). Middle: February 2014 – begin of light intervention (10 room zone stays, 2 outdoor stay). Bottom: February 2015 (12 room zone stays, 3 outdoor stay)

For both intervention groups and the control group the average degree of movement was calculated like for the single person described above. Then the time before the light intervention and the time after the light intervention and for the control group a similar timeframe (measurement period 1 and 2) were compared. The results show only an increase in the amount for stays for the DS-group from M_{DS1} = 13,7 to M_{DS2} = 14,1 whereas in both other groups a slight decrease in stays is observable (from M_{CG1} = 13,8 to M_{CG2} = 13,6; from M_{DN1} = 13,1 to M_{DN2} = 12,4). A similar picture emerges if the time spent outdoors is compared – only the DS-group shows an increase in time spent outdoors (M_{DS1} = 288 minutes to M_{DS2} = 300 minutes; M_{CG1} = 292 minutes to M_{CG2} = 256 minutes; M_{DN1} = 318 minutes to M_{DN2} = 270 minutes). Univariate ANOVA shows for both parameters statistical significant differences ($p < .001$).



Number of indoor and outdoor stays per day lasting longer than 30 minutes
Univariate model explains 29% of variance with p<0,001 (group p<0,001) phase p<0,001

Duration of outdoor stays in minutes per day
Univariate model explains 11% of variance with p<0,001 (group p=0,020) phase p=0,001

Figure 15: Influence of light intervention on mobility.

At the beginning of the study, the individual daily structure of each participant was ascertained to get a picture of the usual daily routine. To know about the initial situation of each person is important, because this information can serve as a leverage point for “improvements” and changes over time can be recognized. The description of the daily structure was done every half an hour. It was necessary to find a daily structure, which covers the daily differences at best. Holidays were not considered.

First, one month after the beginning of recording the PIR-data, the typically stays in the room zones and outside were measured according to the above described evaluation logic. Additionally, the start of the sleeping time was assumed, if there wasn´t any movement in the flat for a particular time after a movement in the sleeping zone. Short interruptions of the sleep, e.g. if a person went to the toilet, were counted, but not interpreted as the end of the sleeping time. This was just the case, if a person left the sleeping zone for a longer time.

The determination of the location are probability statements, which means, it is established how likely the probability of a stay or movement in a specific room zone is. For a selected time the likelihood of stay will exist for several room zones but will be highest for just one room zone, which then will be identified as the location of stay.

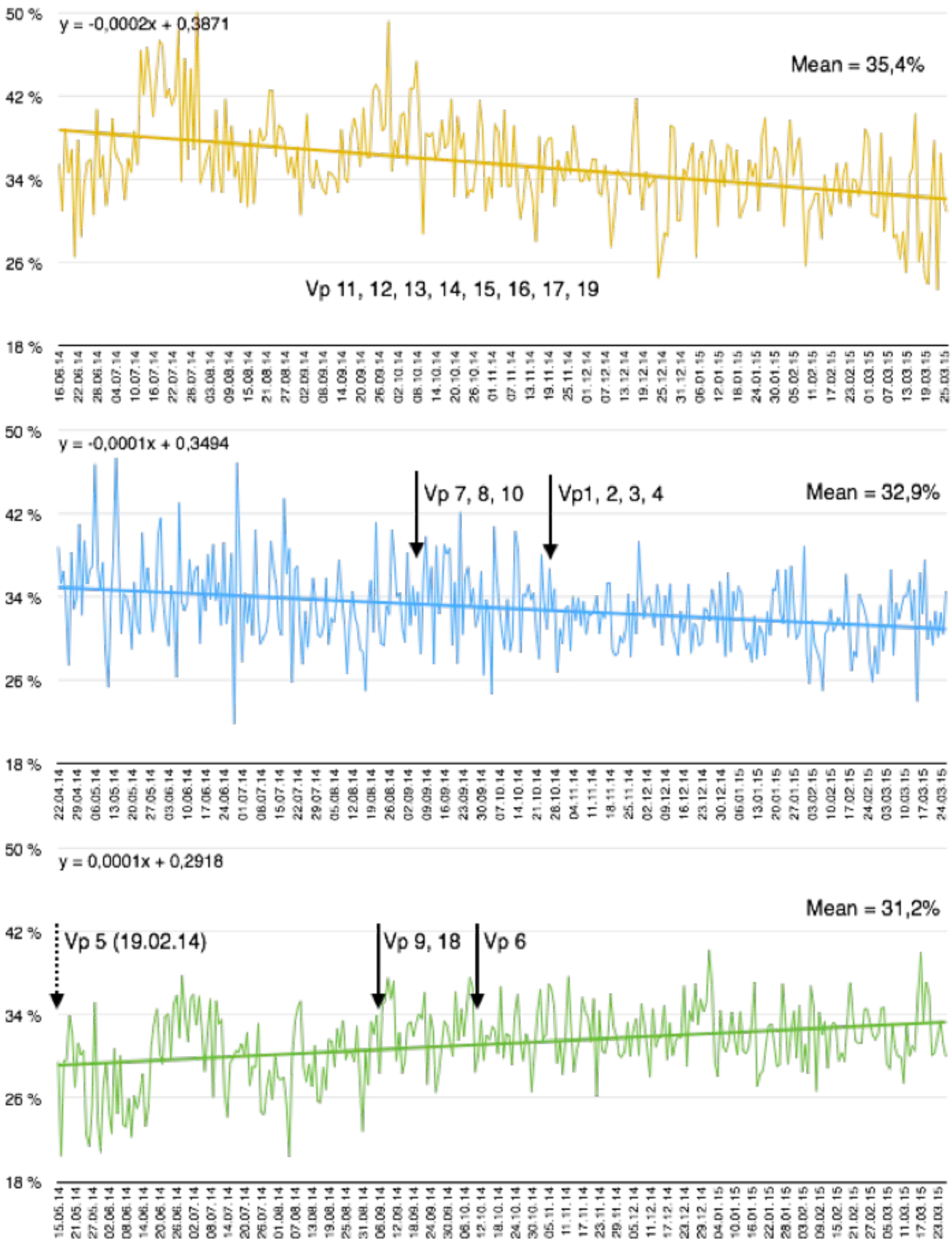


Figure 16: Daily structure fit (a comparison of the individual target daily structure with the always newly determined actual daily structure) in percent. Top: control group. Middle: lighting with day/night-rhythm. Bottom: lighting with daily structure rhythm. Arrows: start of light intervention for resp. test person.

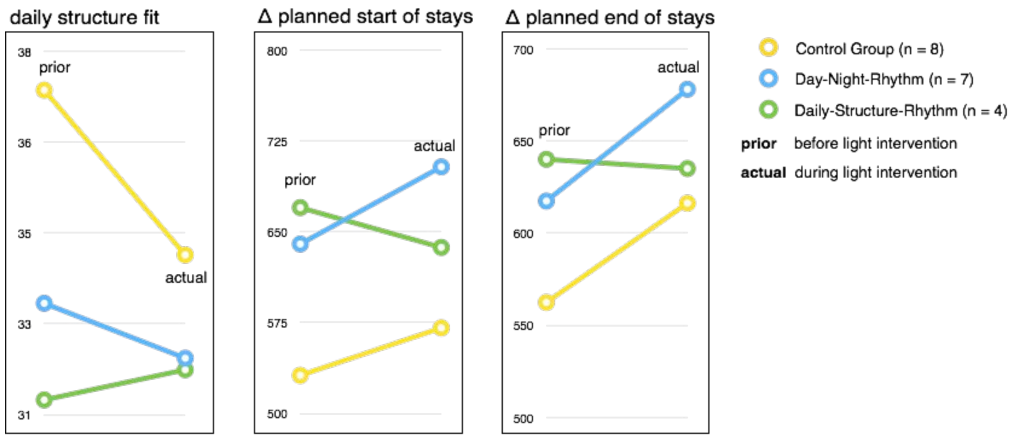
After the determination of the daily structure a conversation with each participant was conducted to discuss, if the identified daily routine is applicable in his opinion, e.g. if he´s at most of the days at a specified time in a particular room zone. The aim was to better understand the daily structure of a person, i.e. to associate the structure with specific activities.

If a participant was sure that there are deviations, the determined daily structure was corrected. With the subjects of the daily structure rhythm illumination, one person who takes care of them and one expert, a target daily structure was defined, which differed a little from the identified actual daily structure (e.g. more outdoor stays). For the subjects of the day-/night rhythm illumination and the control group the identified actual daily structure and the target daily structure were the same.

A comparison of the individual target daily structure with the always newly determined actual daily structure has been done to see how well they fit. If a person always is at the predefined time at a predefined location, the daily structure fit is 100 per cent. Since there was established just one daily structure for different weekdays and even holidays, the expectations regarding the fit of the target and actual daily structure shouldn´t be too high. The daily structure fit of each group (for comparable timeframes) can be seen in Figure 16. The average fitting is between 31 and 35 per cent. It can be seen clearly, that the fit within the CG group and the DN group decreases over time whereas it increases within the DS group. The degree of fit of the DS group isn´t much higher at the end than in the other two groups, but it has to be taken into account, that for the DS group the fit in the beginning was much lower because of the newly defined target daily structure.

If the time before the light intervention is compared with the time after the light intervention (for the control group two comparable timeframes – observation period 1 and 2) it can be seen, that the fit of the daily structure increases slightly for the DS group from M_{DS1} = 31% to M_{DS2} = 32% and decreases for the other two groups (from M_{CG1} = 37% to M_{CG2} = 34%; from M_{DN1} = 33% to M_{DN2} = 32%).

The results of a calculation of the differences between the effective beginning of the stays and the effective end of the stays in the room zones with the target daily structure were similar. Deviation of the beginning of the stay within the DS group decreases from M_{DS1} = 670 minutes to M_{DS2} = 637 minutes and increases from M_{CG1} = 531 minutes to M_{CG2} = 570 minutes for the CG and from M_{DN1} = 639 minutes to M_{DN2} = 703 minutes for the DN group. The deviation of the end of the stay decreases from M_{DS1} = 640 minutes to M_{DS2} = 635 minutes and increases from M_{CG1} = 562 minutes to M_{CG2} = 616 minutes and from M_{DN1} = 617 minutes to M_{DN2} = 678 minutes. Univariate ANOVA shows in the comparison of the two periods for all parameters statistical significant differences ($p < .001$ – $p = .016$).



Percentage of movement detection within individually specified daily structure (all room zones)
Univariate model explains 29% of variance with p<0,001
(group p<0,001)
phase p<0,001

Sum of all starting time deviations of individuals from their daily structure in minutes
(all zones*24*60)
Univariate model explains 23% of variance with p<0,001
(group p<0,001)
phase p<0,016

Sum of all ending time deviations of individuals from their daily structure in minutes
(all zones*24*60)
Univariate modell explains 10% of variance with p<0,001
(group p<0,001)
phase p<0,001

Figure 17: Influence of light intervention on daily structure.

4.1.2 Results of Approach II: day/night structuring

After successfully evaluating the lighting system at each test person´s home, three different light conditions were provided for 0, 2 or 4 hours of duration in the evening (Figure 18 and Table 4). Thus, the effect of the different light conditions on the target variables could be investigated. By repeating the conditions within one test person, the reliability of the effects could be tested, as well.

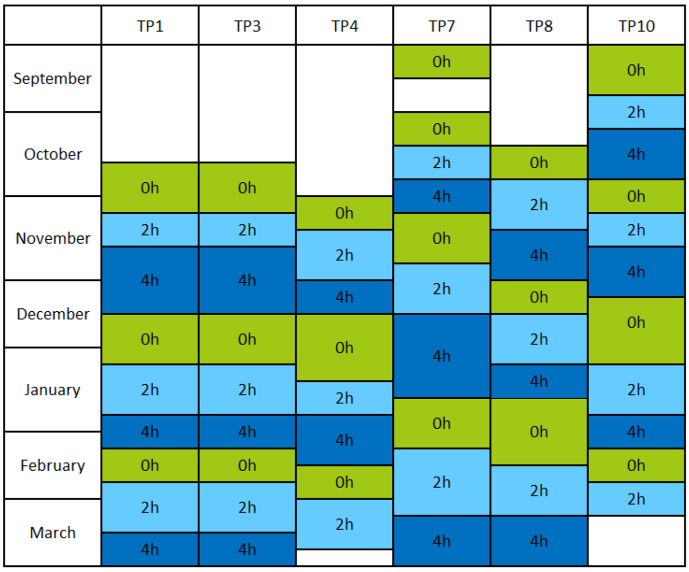


Figure 18: Schedule of three different evening-phases, separately for each test person (column) and each month (row) with its equivalent light condition.

According to the three different durations of light conditions, the 0 hours phase had no impact. Contrary, in the 2 and 4 hours phase the ambient warm-light LEDs were dimmed down to 70% and the task light was dimmed down to 40% as shown in the following small sample.

Table 4: Start and end dates of the light conditions for one exemplary household.

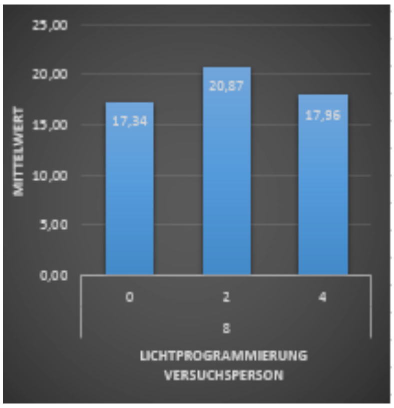
Light conditions	Start	End	Duration of evening condition	Dimming
1.	03.09.2014	19.09.2014	0 hours	Evening condition: not applicable
2.	20.09.2014	07.10.2014	2 hours	Evening condition: ww: 70% / 40%*, cw: 0%
3.	08.10.2014	22.10.2014	4 hours	Evening condition: ww: 70% / 40%*, cw: 0%
Evaluation				
4.	23.10.2014	06.11.2014	0 hours	Evening condition: not applicable
5.	07.11.2014	21.11.2014	2 hours	Evening condition: ww: 70% / 40%*, cw: 0%
6.	22.11.2014	06.12.2014	4 hours	Evening condition: ww: 70% / 40%*, cw: 0%

Data. For analysing the PIR-Parameter (30min timing), test persons 1, 3, 4, 7, 8 and 10 were taken in consideration. Test person 2 had to be neglected due to constant light situation. Furthermore, time calculations, which were shown as 0 values in the Excel output, vacation days, days of absence, the outer zone parameter and data outside the double standard deviation were excluded too. Beside the PIR parameters, the switch data and energy consumption were additionally analysed.

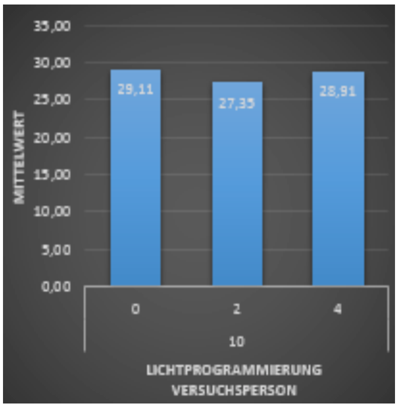
The data was analysed with Excel and the Statistical Package for Social Sciences (SPSS, version 22). For statistical calculations a mean comparison (ANOVA) with Bonferroni correction was used.

Results - PIR sensors. Results showed no significant differences. Analysis of the individual subjects, however, resulted in multiple significant differences between the individual evening phases.

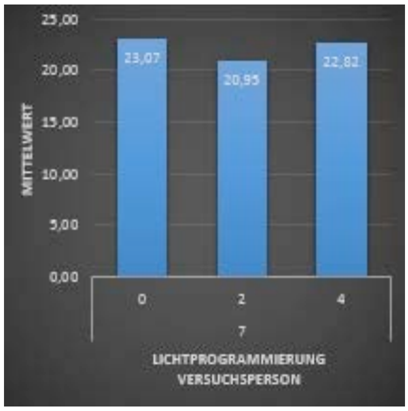
The spatial mobility was calculated with the following parameters: range of motion per day (8 am – 8 pm) or night (8 pm – 8 am) as well as the parameter stays. The parameter stays showed a significant difference in test person 7, test person 8 and test person 10. Further analysis using the post hoc method showed a significant difference in test person 8 ($F(2,133) = 4,900$; $p < 0,009$; Post-Hoc 0-2; $p = 0,013$) and test person 10 ($F(2,169) = 3,194$; $p < 0,043$; Post-Hoc 0-2; $p = 0,050$) between the light conditions with 0 hours and 2 hours duration at evening phase. In test person 7 a difference between the 2 hours and the 4 hours evening phase was found (F(2,134) = 4,069; p < 0,019; Post-Hoc 2-4; p = 0,049).



Test person 8

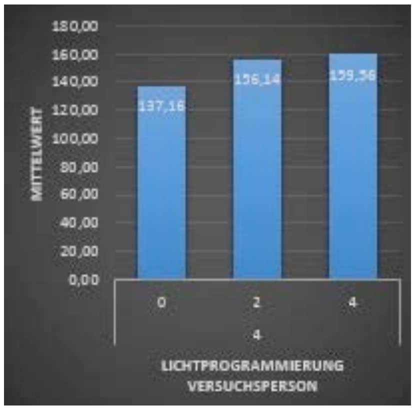


Test person 10



Test person 7

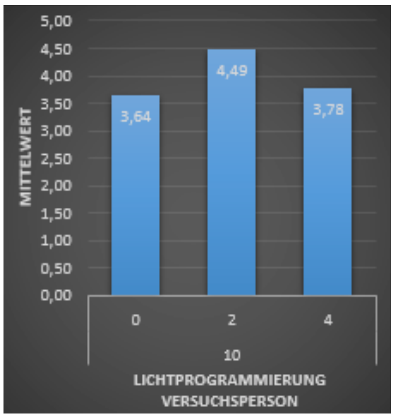
Furthermore, significant results were shown in test person 4 on the parameter range of motion per day (F(2,123) = 3,922; p < 0,022).



Test person 4

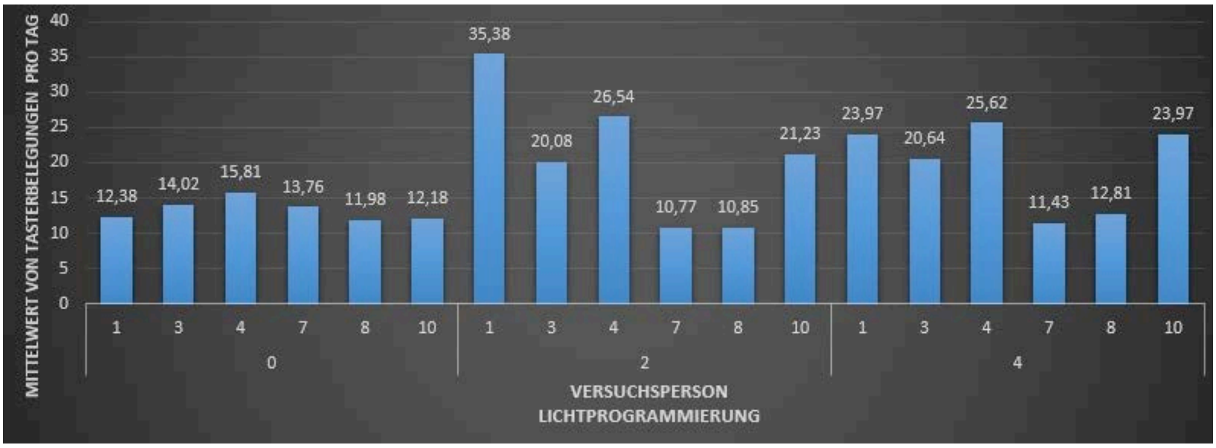
At the temporal mobility, however, significant results were only shown in test person 10, whereby significantly fewer sleep interruptions with 0 hours evening phase relative to the phase of two hours evening were found (F(2,170) = 3,655; p < 0,028; Post-Hoc 0-2; p = 0,030).

Although we strongly believe that there are more significant differences according to the time mobility and the spatial mobility due to the three different light situations, it might be that the PIR-sensors were not sensitive enough, or the time slot was not long enough or the rhythm of 14 days interval was too short. All those influencing factors should be taken in consideration when making generally valid statements.



Test person 10

Results - Light switches. Beside those results, the mean per day of the total amount of the light switches between the different light situations was analysed and is presented in the following figure.



Whereby, the mean range of the 0 hours phase seemed to be very balanced, the daily graphic representation of each test person showed no trend during the same light condition. This was in accordance with the 2 hours and the 4 hours phases.

Consequently, no general valid conclusion when activating the light switches between the three light conditions can be given.

Results - Energy consumption. As shown in the next figure, the maximum mean per day of energy consumption is approximately 2,4 KWh (24.10.14 - 02.03.2015) and the minimum is 0,68 KWh (27.06.14 - 02.03.2015). Hence, the cost of the new and brighter light is between 14,60€ and 4,14€ per month - with an electricity tariff of 0,20€ per KWh. Originally, the price was calculated with approximately 14,40€, which is close to the maximum cost for one month.

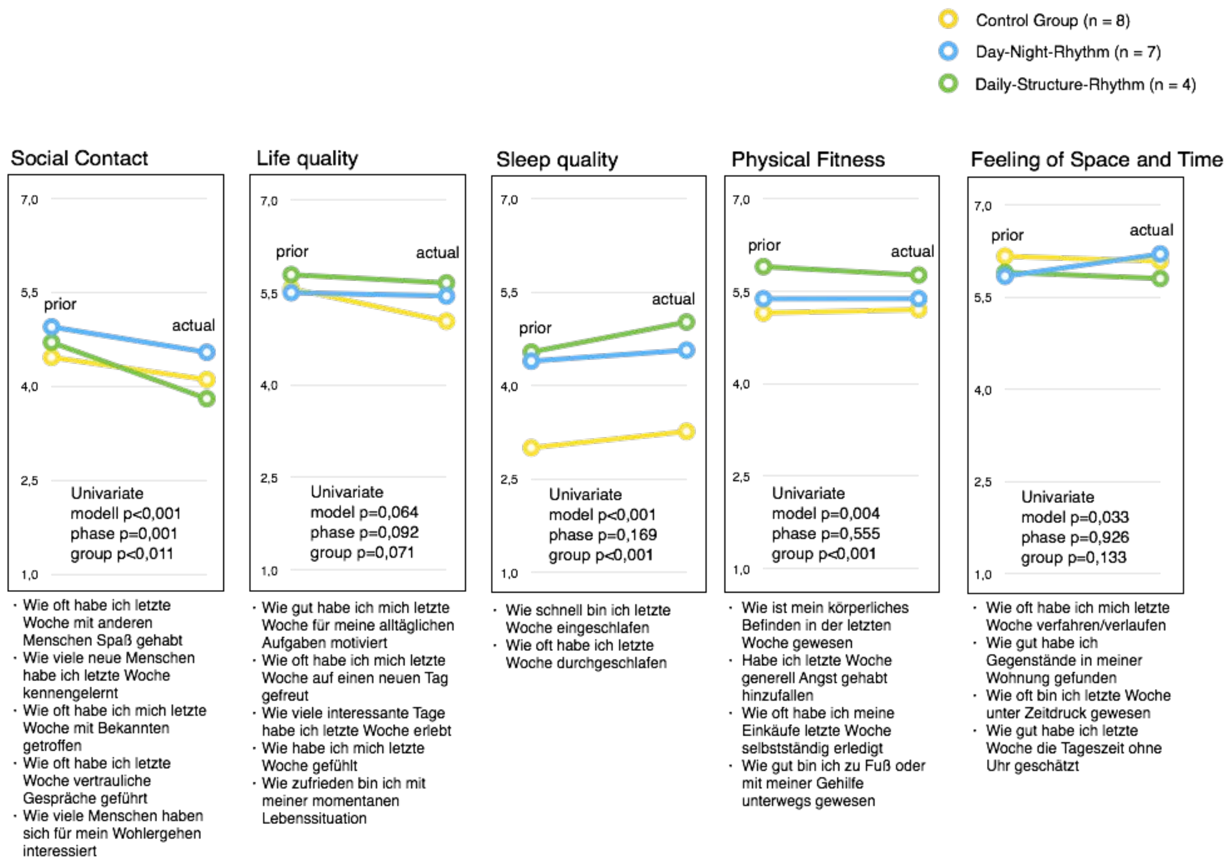
Nevertheless, with the new light conditions, a 10 times brighter and more intensive light than before can be obtained.

4.1.3 Test battery & biweekly monitoring

The biweekly monitoring using the online questionnaires show almost no impact of the light interventions (see figure below). The life quality, the physical fitness, and the feeling of space and time remains roughly the same. Of course, this might be a positive effect, taking into consideration the population of older people, where a decrease of these aspects is commonplace. Nevertheless, we see a slight improvement of sleep quality, which is a well know effect of circadian lighting, used for both approaches of light intervention.

The self-assessment of social contact has been introduced to control this aspect as a confounding variable of light intervention, especially the impact of research staff on test subjects during the study. As we can see in the following figure, the social contact is the only variable with a negative progression. This means, that the positive progessions during the study can't be an effect of additional social contact.

The participants said they hardly could recognize any changes due to the light installation. Therefore, it can be assumed that the effects of Guiding Light are not consciously recognized, maybe because the changes are evolving over a long period.



4.2 Advancements of the lighting system

The field trials offered many occassions fort he consortium to learn and to improve on the lighting system in many different ways. The following sections provide insights that we gained from the empirical data and user feedback.

4.2.1 Technical improvements

Internet access. One major issue, which bound a lot of resources, was providing a stable internet connection. In a first approach we worked with mobile internet access, based on 3G/4G connection. Through the massive loading of client to server connection for activity monitoring the connection broke down several times. This provoked some crashes of software components on controller systems. During the project the cloud servers received between 10 and 30 data packages per second (about 1.5 million records were written per day).

Additionally to the instability of mobile connections the requirement of static IP addresses was a challenge to meet. Static IP is necessary to maintain and configure the lighting system controller components remotely. Standard mobile internet packages use dynamic changing IP addresses and even cut existing connections daily to renew the IP address.

As a matter of fact we encountered several situations with unresponsive light systems in the test households, especially in the early testing phases.

Based on that experience in an early testing phase almost all households were equipped with wired internet connections, static IP addresses and high availability guarantees. The acquired business packages could meet all those requirements but also pushed the costs noticeable.

PIR sensors. Another aspect for ongoing improvements during field test phase was the sleep time of passive infrared sensors (PIR). Sleep time means the pause when a sensor is not scanning for activity nor illuminance to preserve energy. On the one hand we needed sensors with extremely reduced sleep times. Standard sleep time for conventional PIR sensors on market is around 90 seconds to match standard light switching scenarios. The hardware modification for GuidingLight for accurate activity monitoring brought the needed reduction of sleep time to approx. 5-8 seconds. On the other hand we needed to configure individually longer time frames for lights after activity triggering. If some person for example entered the bathroom in order to use the toilet, the timeframe for switching lights off had to be extended to 10 or 15 minutes in some cases, because the testing person didn’t move anymore in the bath room.

We had a surprisingly high failure rate for PIR sensors (approx. 10%). Since every sensor had to be modified manually by changing some electronic parts (resistors, capacitors), we assume that this manual procedure caused some of the sensors to sustain a malfunction. All sensors were tested manually before installation during the configuration process. Possible failure occurred during testing phase in most cases.

In rare cases the PIR sensors fell from the ceiling. In most cases this was either because of problematic surface for the adhesive tape or the required contact pressure during first seconds of installation was not given. In critical cases the magnetic plate had to be srewed into the ceiling instead of using the adhesive tape alone.

Light switches. Some of the electricians did not replace the conventional light switches with switches from GuidingLight (wireless and battery-less EnOcean switches). This led to situations, where the subjects used the conventional switches by mistake and cut the power to the lights. The system seemed to have technical problems, although it was just the switch in off-position. In testing households where old switches were replaced, those situations could not occur.

Some of the documented functional problems were caused by system failure of the controller system. Parts of the light system in testing households or the whole household could not be controlled anymore as well as the automatic light triggering stopped working. The controller systems consists of an embedded computer running a linux environment which hosts the software components responsible for controlling the actuators (lights) and transcomputing the sensors values (PIR sensors, door contacts). Although the responsible partner (MVA) made detailed analysis of those specific situations, some cases still remain unresolved. All situations were logged and have to be examined in further detail. The planned approach is to improve the software in iterations based on documented failure scenarios.

Installation. Some electricians complained about the inconsistent coloring of the wires, which led to wrong assembling in some cases. To be sure the electricians had to measure the current/resistance of the wires to be sure. This inconsistency is a result of the manual prototypic manufacturing of the lamps.

Furthermore, some participants asked for slight adjustments of the lighting positioning or light exchanges, as well as changes in the angle of the lights' positions, which were realized by the consortium.

4.2.2 User Feedback

At the end of the study, all seniors from the intervention group were interviewed to gain insights into their feelings and thoughts during the trials and their final evaluation of the lighting system. The open questions of the half-standardized interview are shown in table x.

The given feedback is now presented, separately for positive and negative feedback that occured during field trials or in the conclusive interview. It is important to underline that no answering options were given to the seniors. Hence, if they claimed that they felt happier or could sleep better, these answers were freely expressed (and not mentioning an aspect did not mean denying the effect).

In general, seniors did like the light a lot, even if they had to endure some technical problems in the beginning, and even though they were not too enthusiastic about the design of the lamps. What is more, all seniors wanted to keep the lighting system after the ending oft he field trials, even those who had initally only agreed to participate because we guaranteed them that they could return to their old lighting system afterwards if they wished to. Furthermore, we received several inquiries from relatives, health care persons or members of the control group about the price and availability of the lighting system.

So, overall, the lighting system was a big success with regard to the subjective feedback of the test users.

What test persons **LIKED** about the lighting system (see also Figure 19):

- **Good task light:** The most often mentioned positive aspect of the lighting system was the good light quality. Seniors mentioned to see much better now, for instance when cooking or playing cards with friends. One senior told us that one of her friends, who has health problems with her eyes, was happy that she could see the cards much better now, so she insisted on playing cards always at the apartment equipped with our lighting system instead of alternating them. In another case, the chiropodist was absolutely thrilled about the light and stopped bringing its own light to the apartment because she felt it was not necessary.
- **Bright Ambient light:** Seniors also mentioned the comfortable and glare free ambient brightness of their flats with the new lighting system. Senior flats, especially in assisted living, are often quite small, and balconies from above, but also trees or the position oft he windows led to quite dark flats before the light installation. In comparison, seniors described the new light as „being bright without the impression of typical lamps".
- **Automatic switching:** Interestingly, seniors were quite sceptical about the motion-triggered control of the ambient light. As one participant put it, „if I cannot switch on my lights on my own anymore, then it's over anyway". They could not imagine the advantage it could mean to them in the beginning. At the end of the field trials, participants uniformly said that this function was among the most positive characteristics of the lighting system, perceived as raising the comfort and reducing the costs. They enjoyed the comfort of just walking around and getting the right light automatically. On the other way round, it was also experienced as extremely comfortable to go to bed with the lights on and just wait there for a moment until they switched off on their own. As one senior said, it is very helpful especially in the morning when agility is still low and she needs her hands to support herself on the walls of her apartment to move around that the lights react automatically.
  In one case, a burglary was most probably prevented thanks to the light, because a neighbouring flat was robbed, and there were also hints of forced entry, but nothing was stolen in the test apartment. It is plausible to assume that the burglar was put to flight because of the light switching on when entering the flat.
- **Interface:** In another case, there was a caretaker who sometimes entered the apartment unquestioned and sniffed around, according to the inhabitant. Since the installation of the system this never happened again. The testing person was happy to have some evidence of movement inside her apartment via the interface if she was away and it would happen again.
  Furthermore, activity patterns could detect sudden health deteriorations quite well: If technicians discovered for instance that a person lay in bed for extraordinary long times and the contact person made a call to investigate the reasons (or make sure that the sensors were not broken), seniors reported being sick, having suffered from a stroke or similar severe events.
- **Social effects:** Seniors reported that especially visitors were thrilled by the quality of the light and the technical sophistication of the system. For instance, neighbours were quite curious to see the new light and came by to have a look at it. Others asked the

participants about the nice bright light that they could see from outside in the evening hours when it was dark.

- **Subjective improvements in wellbeing:** Even thought the questionnaire and PIR data did not deliver considerable proof of effect, the seniors reported about feeling better and happier, about an enhanced drive or better sleep quality. As mentioned before, this is even more remarkable given the fact that the interviewers did not explicitly suggest these effects.

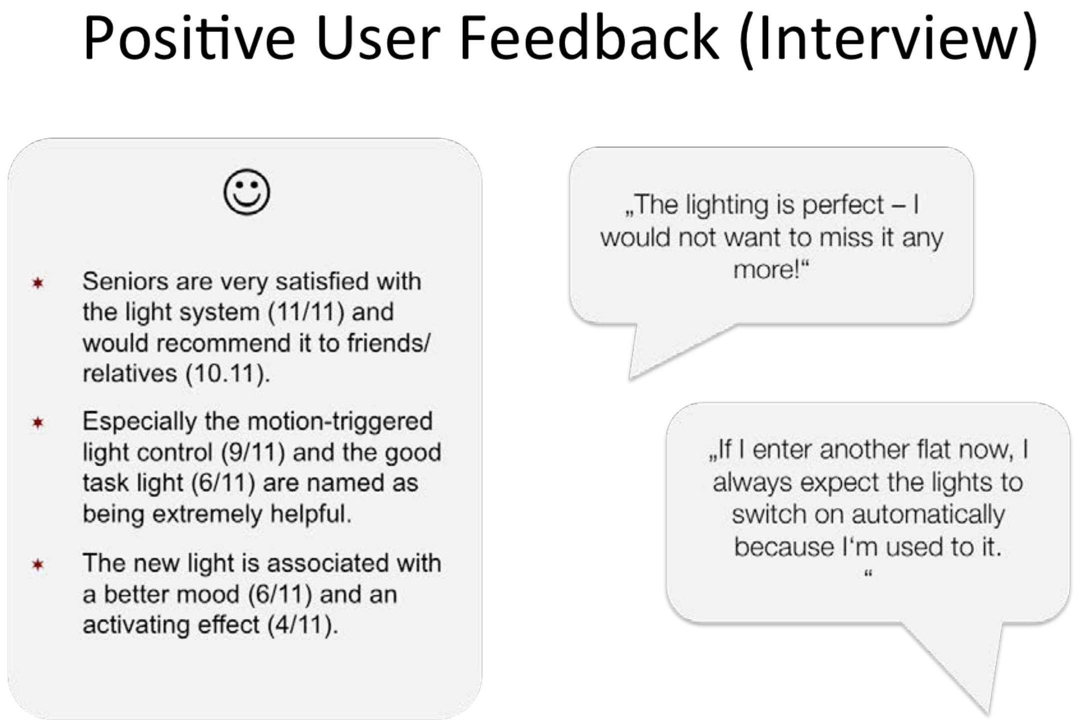


Figure 19: Positive Feedback of the intervention group (N=11) given during the final qualitative interview at the end of the field trials

What test persons wanted to be **IMPROVED** about the lighting system (see also Figure 20):

- **Lighting system (in general):** When asked how to improve the lighting system, the wish for controlling the brightness individually (instead of a predefined light curve) was mentioned. Furthermore, some seniors asked for a label for the light switches, or suggested to deliver a remote control with the light system.

- **Light characteristics:** An often posed question was whether the follow-up time of the lights could be prolonged, especially in the bath room. It sometimes happened that motion in the shower was not captured by the PIR sensors because it was hidden by the shower curtain, leaving the seniors in the dark after some minutes while washing their hair. In these cases, the times were prolonged until these events could be prevented. If lights turned out while sitting still at the table reading, seniors learnt to switch on the light by arm movements that could be detected by the PIR sensor. One senior even clapped her hands to do that, which led to huge excitement among her grandchildren.
  Other subjects remarked individual preferences in light color. One person wanted to

have cold white to be present longer in the evening, even if she knew about the effects on sleep and activeness.

- **Cleaning:** Lamps are difficult to clean. Especially the acrylic cover of the pendant light makes dust and dead insects through its transparency much more visible, than on conventional surfaces (thus it's nickname „insects' cemetery"). One test person was afraid of cleaning the pendant light because of the small gap inside the side cover. The person didn't want to have dust falling inside the lamp during cleaning, so she completely spared it out.
- **Design:** Regarding the design of the lights (especially task lights and downlights), some seniors felt they reminded them of a hospital or care house. In single cases (e.g. for test person 18), single lights were thus removed or exchanged.

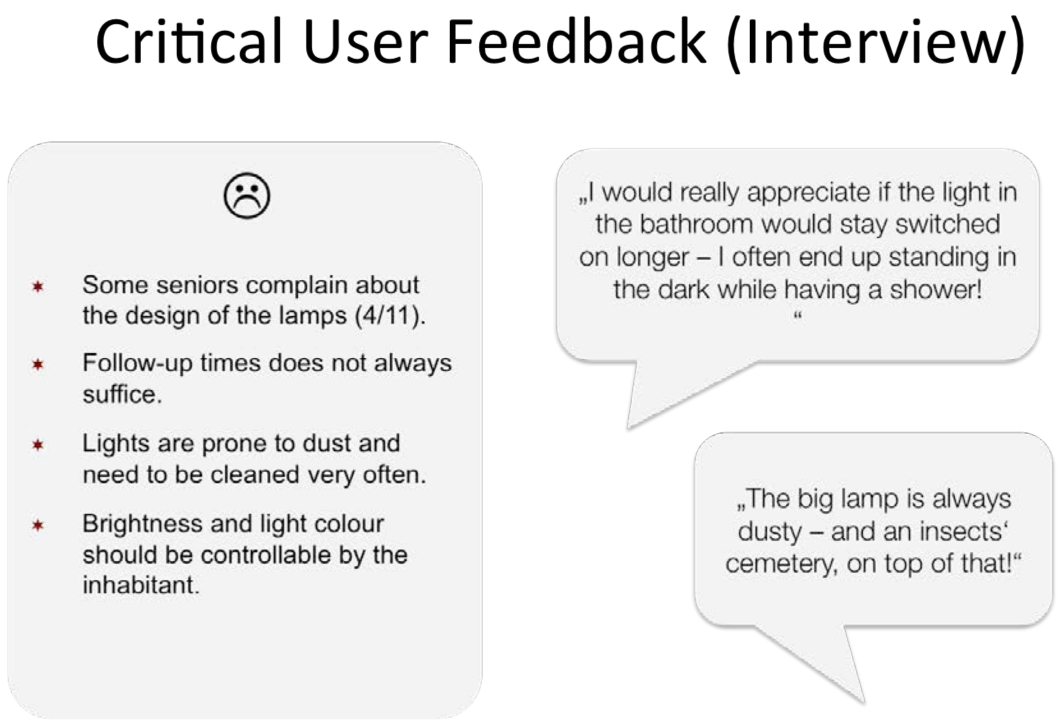


Figure 20: Negative Feedback of the intervention group (N=11) given during the final qualitative interview at the end of the field trials

4.3 Advancements of the user interface

In line with our participatory and iterative development approach we carried out both heuristic inspections by experts in the development phase and end-user tests in field test phase. Given our specific target group, i.e. older people with various impairments such as diminished vision, the user interface of Guiding Light for primary enduser had to conform not only to general usability guidelines, but also to accessibility guidelines, more specifically WCAG 2.0, which were published as a W3C Recommendation on 11 December 2008.

Since in the course of our user requirements analysis it emerged that an internet access could be found in virtually all households and care organisations, it was decided to implement all

Guiding Light user interfaces for web browsers. We assumed that our target users would be familiar with handling touch screens but the usability tests during filed study show, that it is perceived as too complex and difficult to use by many. They would prefer buttons, which are integrated with a display to inform users about what they have to do next.

The primary enduser as test persons had no particular suggestions for navigation in addition to the well-accepted rules such as to always show the user's own position within the software structure, to offer a return to the starting point and give immediate feedback after every user action. The majority of test persons preferred white text colour and blue background colour and were not interested in history information extending for more than seven days (e.g. mobility monitoring).

Several general observations could be derived from these early user tests:

- Users expect immediate confirmation or feedback from the system.
- The number of menu items to choose from should not exceed five or six items.
- (Semi-)technical terms (e.g. motion senors) have to be replaced with simple ever-
- day terms.
- Users prefer an information structure with a very flat hierarchy

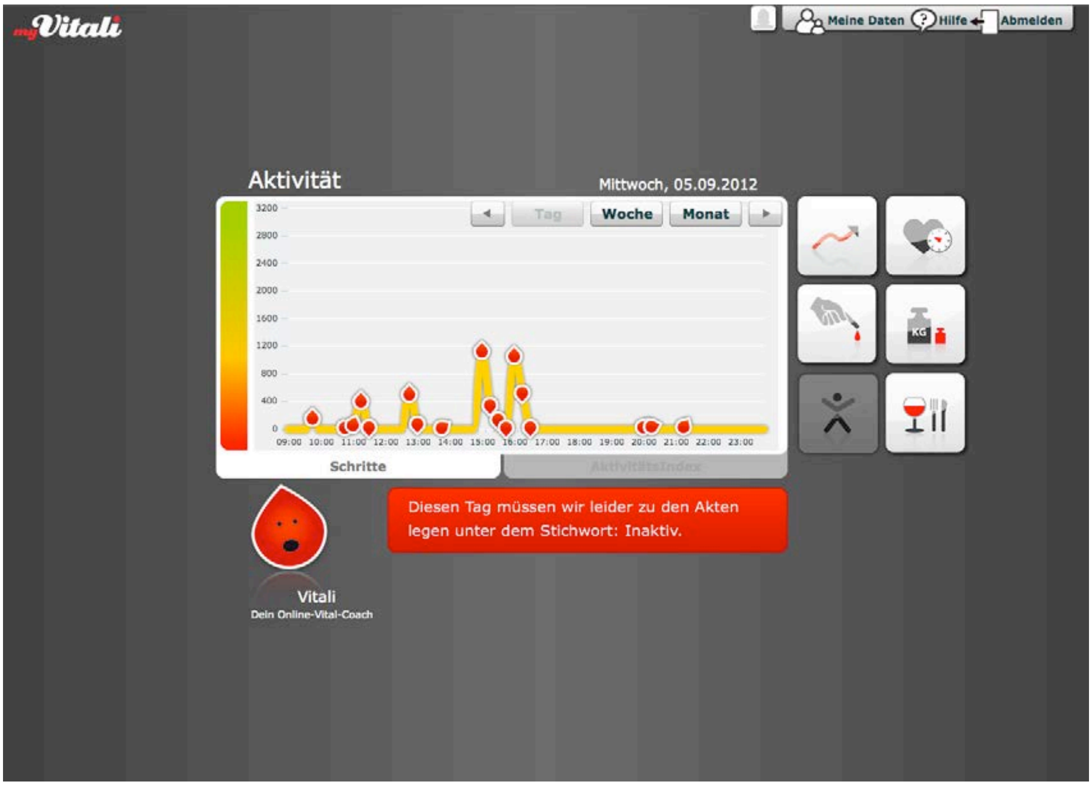


Figure 21: User interface for primary enduser for monitoring individual mobility.

Besides the user interface for primary enduser we had developed user an interface for the secondary enduser (e.g. relatives, care persons), where they can monitor the mobility of older persons. User feedback shows, that this is a powerful instrument which can be effectively used by amateurs after short introduction.

Figure 22: User interface for secondary enduser for monitoring individual mobility.

5. Conclusions

The experiences with Guiding Light highlights the advantages of LED illumination regarding controllability and light bundling, if they are suitably programmed. The use of Guiding Light with programmed daily structure rhythm increased the motility (individual amount of body motion) and mobility (individual number of indoor and outdoor stays) of the participating residents. Furthermore, the increasing daily activity fits the individual daily structure better (individually planned locomotion). These findings are based on the analysis of PIR-sensor data, which were gathered continuously without any help of the participants. The participants said they hardly could recognize any changes due to the light installation. Therefore, it can be assumed that the effects of Guiding Light are not consciously recognized, maybe because the changes are evolving over a long period.

Nonetheless, a replication study with a bigger sample seems promising. The study indicates that people can be guided to specific places at particular times through a spatial and temporal configuration of the light intensity and light colour of LED-lamps. Further research is necessary to confirm the findings of Guiding Light and generalise the results that by means of coordinated interaction of ambient room lighting and focussed room zone lighting "the right amount of activity at the right time at the right place" can be achieved.

In addition to the field tests, there were several final end-users and end-user organizations who participated in our user-centered design process of Guiding Light. For the purpose of context analysis and investigating end-user requirements, we interviewed caregivers, gerontologists, physiologists, and physiotherapists from end-user organizations at the very beginning of our project. We are always in close contact with end-user organizations who are participating in field tests (e.g. Seniorenwohnpark Vaterstetten GmbH, Sozialdienste Götzis GmbH). During initial contact with our test subjects, we also investigated their requirements for structuring the daily live and the use of lighting within their accommodation. In the course of software development, we conducted paper prototype evaluation together with several seniors and care personnel. We compared expert user interfaces on how easy it is for care experts to accomplish tasks with the application by using cognitive walkthrough methods. We iteratively redesigned older person's user interfaces on the basis of usability testing with seniors.

Some partners of the project consortium have acquired a lot of know-how and have conducted intensive requirements analysis concering ambient assisted lighting solutions before the start of this project. Additionally, we have compiled the core publications on the subject of user requirements imposed on the light solutions for older people and brought all this knowledge together in Deliverable 1.1. Focus groups, storyboards, cognitive walkthroughs etc. are not suitable methods for Guiding Light in the runup to product development because end-user must simply experience lighting in order to give feedback. This is why we made rapid iterations progress immediately visible to allow frequent optimization. Beyond this, we have a systematic approach for addressing end-user demands during field tests. These activities include in-depth interviews with involved seniors, caregivers, family members, and psychologists as well as questionnaires with involved seniors every other week in order to gather information about the usability and accessibilty of the installed Guiding Light system (hardware and software), as well as about the daily structure and the mobility changes of the senior participants. We took into consideration data from mobility monitoring into these focus groups. Our overall approach met the Description of Work since we started end-user participation with the beginning of the project and finished it with the end of project (participative design). This kind of long-term end-user involvement seemed to be an essential approach in our case because requirements concerning subliminal product stimuli in small quantities (i.e. lighting) cannot be raised immediately after confronting with this new product but only within a prolonged time period of using this new lighting system.

5.1. Lessons learnt regarding the GuidingLight system

As a result from the installation process we see a variety of improvements, which should be considered progressing towards the market. Most of those improvements were not possible through the project phase, either because of missing experience, the small number of households (prototypic approaches instead of mass production) or just as a matter of limited budgets.

To speed up installation process, it is considered to integrate all wireless actuators into the lamps before installation and also do the learning process to link actuators to light switches and backend nodes. The current approach was to assemble the lamps, send it to the households, where the actuators were linked and embedded in some additional panels. Since the previously used type and vendor of actuators was exchanged during project and the newer version was smaller, it would be possible to embed them into the lamps instead putting them into additional panels mounted on ceiling or walls. The newer actuators are much smaller and can control two channels instead of one single channel. The idea is to configure and assemble the whole system to be ready to just be attached to the electric power. This will reduce costs of preparation and installation by factors. Discussions towards this direction are already ongoing within the project consortium.

Hardware installation on site can be accomplished with a local electrician, but a qualified briefing and supervision has to be taken into account. For refurbishment issues the wireless solution is strongly outcasting the wired solution. The wired solution is only suitable for buildings under construction or rather if the building is already equipped with an electrical bus installation. Based on the experiences of the installation of the test households the lighting design guidelines are adequate. An "installation handbook" with detailed description of luminaire orientation is needed.

5.2. Lessons learnt regarding end users

These are our main insights about working with seniors from the field trials:

- **The challenge of recruiting participants:** The hardest lesson to learn was the challenge of finding suitable and willing seniors, or senior facilities that consented to participate in the project. As mentioned before, retirement homes as partners have difficulties with the workload of their staff anyway, and those willing to participate in projects are often already involved in one or more. In most cases, personal contacts were the only way to find suitable candidates because a relationship of trust already existed. Some seniors were afraid that this was a way of trying to sell the light system in the end and were afraid of being cheated. Recruiting might have been much easier if an international senior organization had been part of the consortium.

- **Fear of electromagnetic pollution:** When seniors learnt that the lights are controlled wirelessly with EnOcean-Switches and actors installed into the lamps, concerns about electromagnetic pollution were repeatedly expressed. It became clear that this might be a major obstacle at the market for a guiding light system.
  In order to appease these fears, the consortium compiled an information sheet about the electromagnetic emission of the used components, including the following information:
  - An EnOcean radio telegram produces a 100 times less intense electromagnetic pollution than a conventional light switch. Due to the spark generated when conventional switches are closing the circuit, also an electromagnetic field is generated.
  - Each live cable is generating a magnetic field or low frequency electromagnetic emissions. By avoiding power cables to and from the switches, a large part of these emissions is avoided.
  - As comparison the exposure of DECT phones (cordless phones). They send an average of 10mW (but steady) and a maximum of 250mW of transmission power. WLAN sends power to a maximum of 100mW. A mobile phone can send more than 1000mW of power for poor mobile receiption. EnOcean transmits with a power of 10mW, but only at the time of shipment from the telegram (fraction of a second). In field study case, of course, the messages accumulate through the monitoring activity. However, the transmission power is in sum still far below the above-mentioned devices that are permanently on reception or in contact with the base station.
  - More detailed information can be found here:
    http://www.enocean.com/de/safety-human-health/
    http://www.enocean.com/fileadmin/redaktion/pdf/articles/ECOLOGMessgutachten_v1.1.pdf
- **Fear of high electricity costs:** Data from overruling the automatic light switching in the evening hours when it became darker outside shows that seniors had difficulties enjoying the good light because they were used to sparing light (i.e. money) and thus felt the urge to switch the light out manually very often. Even though we ensured them right from the beginning of the project that costs would remain stable while they would get much more light for it (due to LED technology), they obviously could not stop themselves from sticking to their used sparing behaviours.
- **The installation:** For some seniors (many of them aged above 80 years), the installation of the lighting system was a demanding event. It took electricians several days until the change from the old to the new lighting had been finished, and in some cases, works were interrupted for 1 day before they could be finished. Apart from the dirt and foreign people entering the flat, or the door being open for the whole day, the change itself and the disturbances of daily routines had some negative effects. Furthermore, seniors were partly overwhelmed by the number of lamps and cables and did not like the design of the new system at first. Thus, it was very important that the accompanying partner (supervisor) was present at least during the first day of the installation to exert a calming and positive effect on the seniors.

- **Failures of the lighting system:** Even though the components had been tested extensively before they were implemented in the field trials, we still faced some problems repeatedly that demanded some endurance from the participants. This confirmed our initial decision to use (cognitively and emotionally) fit seniors that could cope with these problems in an admirably confident and sober way (given their age!). Little presents (some chocolate, flowers, fresh fruits) were also made from time to time to esteem the seniors' cooperation and as a little thank you.
  For the supervising partners, however, taking care of up to 4 households with a repeatedly failing light system turned out to be very demanding at times. De facto, a 24/7 availability had to be guaranteed, including holidays and weekends, so that seniors could call the mobile phone of their supervisor at any time if the lighting did not work anymore. Sometimes, simply withdrawing the controller and gateway from electricity for some seconds helped to solve the problem (a technique the seniors learned to use by themselves by the time), but often technical partners (located in a different country) had to be consulted because only they could help. Since field trials lasted – depending on the household – from 4 months until more than a year – the supervising task meant an extra effort that was not covered by the efforts calculated in the proposal.
  Since some rooms did not have any windows (bathrooms) and system failures occurred about once a week for some households at the beginning of the field trials (mobile Internet), providing a torch or something similar to the seniors might have been a good idea. (Note: One senior received one as a present from a friend whom she had told about the new lighting system as a joke.)
  What surprised us was the fact that some seniors did not call immediately if the system broke down, but waited up to several days claiming that they could cope with the natural light well enough. In order to prevent such situations, we implemented a failure warning system into the light control by the end of the field trials.

- **Senior behaviour:** Most of the seniors had not trouble to fill in the biweekly questionnaire, but some of them needed help to do it, so that we used telephonic interviews instead (which might have influenced the answers because of the missing privacy).
  Regarding expense allowance, we learned that money might be a motivator for some seniors, but for the majority it is not. Thus, some partners paid the seniors a reimbursement (100 EUR / month) to reward the time spent with the numerous tests and questionnaires, as well as the trouble with the failures of the prototype (especially in the beginning). It might also have helped to overcome reservations about higher electricity costs. However, we got the impression that less incentivation (e.g. 50 EUR/month) might have also been sufficient. Seniors were rather motivated by the drive to contribute to something new and useful.
  Regarding the acceptance of the system, we learnt that relatives and friends have a huge influence on the participants' attitude towards the lighting system. For instance, if children praised the light and expressed their positive feelings about it, seniors seemed to be more positive, as well. On the other hand, if children worried about the costs of maintaining the system or claimed that it was not any better than regular lamps from furniture shops or electrical retail, seniors started to worry, as well. In future projects, it

might therefor be useful to include the relatives stronger than we did in the GuidingLight project.

- **Exit strategy:** Luckily, system failures could be reduced to an absolute minimum during the project course, so that we could offer the seniors or facilities to leave the system installed, being optimistic that maintenance will be possible without major services. Thus, a contract was signed with the private seniors or involved facilities to commit the installed systems officially. For this purpose, a brochure-like file was compiled including the contract, the original invoices of the components and fact sheets, as well as a to-do-list in case of different types of failures that might occur. It was agreed that the groundkeeper or affiliated electrician will be the contact person from May 2015 (end of project) for the inhabitants, and if everything else fails, the technical partner offer their support (for money). Contact data of all technical partners were included, as well.
  Regarding the social contact between the supervising persons and the participants (who had been communicating for several months regularly), we will stay in contact with the seniors for a little chat or date from time to time.

5.3. Outlook

New technological components will be available in the near future to make Guiding Light product cheaper, more flexible, aesthetically more appealing. Technical optimization potential can be found in the utilization of directly wireless controllable electrical ballast. Prototypes were already shown by industry (e.g. at the fair "Light and Building" in April 2014 in Frankfurt). Readiness for market is predicted for 2015. Such electrical ballast will tighten the amount of components and decrease the technical complexity (e.g. wiring amount on site is decreased to possible minimum, which is only the power supply).

Four levels of exploitation are under work:

1. Smart home planning and implementation (MVA)
2. Lighting design (Bartenbach)
3. App development (FHV)
4. AAL advice (Apollis, Youse)

If one partner will be requested for a Guiding Light system, residual services of other partners will be included.

Annex I: Consent form

Projekt „Guiding Light“ (AAL 2011-4-033)
Ambientes Lichtleitsystem zur Mobilitätsunterstützung älterer Menschen

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Einverständniserklärung Studienteilnehmer/in

1. Ich habe ausreichend Informationen zu dieser Studie erhalten, hatte die Möglichkeit Fragen zu stellen und verstehe die Inhalte.
2. Mir ist bewusst, dass die Teilnahme freiwillig ist und ich jederzeit ohne Angabe von Gründen von der Studienteilnahme zurücktreten kann, ohne dass rechtliche Konsequenzen für mich entstehen.
3. Ich weiß, dass im Rahmen der Studie persönliche Daten von mir erhoben werden soweit dies für die Zielsetzung der Studie erforderlich ist.
4. Ich weiß, dass alle meine Daten der Schweigepflicht unterliegen und sie für Dritte unzugänglich gelagert werden. Alle meine Daten werden verschlüsselt (pseudonymisiert) gespeichert und verarbeitet, so dass ein Rückschluss auf meine Person nicht möglich ist (zum Beispiel ID01 an Stelle meines Namens).
5. Ich weiß, dass im Falle meines Rücktritts alle pseudonymisierten Daten auf Wunsch vernichtet werden und bereits anonymisierte Daten nicht gelöscht werden können.
6. Ich bin damit einverstanden, dass die Ergebnisse der Studie veröffentlicht und für zukünftige Forschungszwecke verwendet werden dürfen, ohne dafür eine erneute Einverständniserklärung von mir einzuholen.
7. Ich weiß, dass ich kein Anrecht auf finanziellen Erfolg habe, der sich aus den gewonnenen Erkenntnissen aus der Studie eventuell ergibt.

Ich habe diese Einverständniserklärung persönlich gelesen.

Mit der Erhebung und Verwendung persönlicher Daten nach Angaben der Studieninformation bin ich einverstanden.

Ich stimme der freiwilligen Teilnahme an dieser Studie zu:

Vorname, Name: ____

Ort, Datum: ____

Unterschrift: ____

Erklärung der aufklärenden Person:

Ich habe den/die Teilnehmer/in zu den Inhalten dieser Studie informiert und Fragen ausreichend beantwortet.

Ich bin überzeugt, dass der/die Teilnehmer/in die Studie verstanden und diese Einverständniserklärung aus freien Stücken abgegeben hat.

Vorname, Name: ____

Ort, Datum: ____

Unterschrift: ____

Annex II: Description of participants

Test Person	
TP1	❧ Gender: female, ❧ Born in: 1928 ❧ Eyesight: needs glasses ❧ Mobility: needs a rollator outside of the appartment ❧ Care Level: none ❧ Chronic diseases: none ❧ Activities: domestic music once per week ❧ General condition: good ❧ Group: GL deluxe (PIR + Light) o Baseline measurement: 14.02.2014 and 19.02.2014 o Installing light system: performed in February 2014, 4 days of work, termination at 03.03.2014 o Start PIR data collection: 23.04.2014 o Start monitoring survey: 27.03.2014 o Start light Programming: 24.10.2014 o Endline measurement: 24.02.2015, 26.02.2015, 09.03.2015
TP02	❧ Gender: female ❧ Born in: 1934 ❧ Eyesight: good after cataract operation ❧ Mobility: almost none ❧ Care Level: none ❧ Chronic diseases: high blood pressure ❧ Activities: adventurous, domestic music, memory training, hiking, holiday trips ❧ General condition: good, has problems to fall asleep ❧ Group: GL deluxe (PIR + Light) o Baseline measurement: 14.02.2014 and 27.02.2014 o Installing light system: 24.-28.4.2014 o Start PIR data collection: 28.04.2014 o Start monitoring survey: 27.03.2014 o Start light programming: 22.10.2014 ❧ Endline measurement: 23.02.2015 + 26.02.2015
TP03	❧ Gender: female

	❧ Born in: 1935 ❧ Eyesight: needs glasses, bad eyesight (has a macular degeneration) ❧ Mobility: has problems with walking, needs a rollator ❧ Care Level: none ❧ Chronic diseases: polyneuropathy, gait ataxia (cerebellum), epilepsy ❧ Activities: memory training, goes sometimes into the canteen for lunch, does once per week the shopping with her son, ❧ General condition: is insecure during walking because of absence of feeling in the feet, but mentally healthy ❧ Group: GL deluxe (PIR + Light) o Baseline measurement: 14.02.2014 and 27.02.2014 o Installing light system: 5.03.2014 except light in the bathroom, concluded on 12.03.2014 o Start PIR data collection: 12.03.2014 o Start monitoring survey: 27.03.2014 o Start light programming: 22.10.2014 ❧ Endline measurement: 24.02.2015, 26.02.2015, 09.03.2015
TP04	❧ Gender: female ❧ Born in: 1946 ❧ Eyesight: bad (myopia, needs glasses to watch tv, sees really bad especially in the evening) ❧ Mobility: limited (needs walking aid, rollator) ❧ Care Level: none ❧ Chronic diseases: heart problems, high blood pressure, thyroid, osteoporosis, arthrosis, rheumatism (had a heart attack and an apoplexy, since end of 40s in premature pension) ❧ Activities: plays often on the computer (e.g. card games, domino) ❧ General condition: mentally healthy, but has often pain because of rheumatism and osteoporosis, sometimes lack of enthusiuasm ❧ Group: GL deluxe (PIR + Light) o Baseline measurement: 12.02.2014 and 19.02.2014 o Installing light system: start on 21.05.2014, concluded two weeks after beginning o Start PIR data collection: 12.02.2014, last PIR-Sensor over bed on 27.03.2014 o Start monitoring survey: 27.03.2014 o Start light programming: 22.10.2014 ❧ Endline measurement: 05.03.2015
TP05	❧ Gender: female ❧ Born in: 1928 ❧ Eyesight: good

	❧ Mobility: good ❧ Care Level: none ❧ Chronic diseases: none ❧ Activities: plays regularly cards, sings, does gymnastics, goes for a walk if she didn´t have enough movement during the day, lunch in the canteen, but she cooks as well ❧ General condition: good ❧ Group: GL deluxe (PIR + Light) o Baseline measurement: 8.10., 14.10., 17.10., 30.10.2013 o Installing light system: 01.06.2013 – 30.09.2013 o Start PIR data collection: 22.10.2013 o Start monitoring survey: 30.10.2013 o Start light programming: 19.02.2014 o Endline measurement: 17.02.2015 + 27.02.2015
TP06	❧ Gender: male ❧ Born in: 1933 ❧ Eyesight: right eye good, left eye blind ❧ Mobility: needs a rollator or crutshes, signs of wear and tear in the back, aftereffects of stroke ❧ Care Level: has one, but doesn´t know which one ❧ Chronic diseases: none ❧ Activities: plays cards regularly ❧ General condition: not very mobile, goes with rollator for a walk ❧ Group: GL deluxe (PIR + Light) o Baseline measurement: 8.10., 14.10., 17.10., 30.10.2013 o Installing light system: 01.06.2013 – 30.09.2013 o Start PIR data collection: 22.10.2013 o Start monitoring survey: 30.10.2013 o Start light programming: 19.02.2014 o Endline measurement: 25.02.2015
TP06 neu	❧ Gender: male ❧ Born in: 1949 ❧ Eyesight: really good, need sometimes glasses to read small texts ❧ Mobility: has sometimes some difficulties to stand up after sitting ❧ Care Level: 4 ❧ Chronic diseases: depression ❧ Activities: goes shopping by himself, lunch in the canteen ❧ General condition: lack of enthusiasm, forgets increasingly to go for lunch ❧ Group: GL deluxe (PIR + Light)

	- Baseline measurement: 15.09., 17.09., 21.09.2014 - Installing light system: takes over the installation of the former resident - Start PIR data collection: 21.08.2014 - Start monitoring survey: 11.11.2014 - Start light programming: 10.09.2014 - Endline measurement: 27.02.2015
TP07	- Gender: Female - Born in: 1949 - Eyesight: no glasses - Mobility: good, no walking aid - Care Level: none - Chronic diseases: no - Activities: volunteering at Caritas, agile and active in the garden (Ground Floor) - General condition: good - Group: GL deluxe (PIR + Light) - Baseline measurement: 11.02., 19.03., 24.03.2014 - Installing light system: complete (performed by electrician "Schweinester" in February 2014, 4 days of work, termination at 03.03.2014) - Start PIR data collection: 03.03.2014 - Start monitoring survey: 12.03.2014 - Start light programming: 11.06.2014 - Endline measurement: 26.02.2015
TP08	- Gender: female - Born in: 1946 - Eyesight: no glasses - Mobility: good - Care Level: none, sleeping problems - Chronic diseases: none - Activities: no special contacts, moved into apartment with August 2013 - General condition: good - Group: GL deluxe (PIR + Light) - Baseline measurement: 05.02., 11.02.2014 - Installing light system: the 12.3.14 started (operated by electrician Schweinester), concluded on 20.3.14 - Start PIR data collection: 03.03.2014 - Start monitoring survey: 19.03.2014 - Start light programming: 11.06.2014 - Endline measurement: 26.02.2015

TP09	❧ Gender: female ❧ Born in: 1949 ❧ Eyesight: needs glasses just for reading ❧ Mobility: good ❧ Care Level: none ❧ Chronic diseases: none ❧ Activities: playing in an orchestra for 34 years, agile and often in the city ❧ General condition: good ❧ Group: GL deluxe (PIR + light) o Baseline measurement: 25.05.2014 o Installing light system: four days of work (operated by electrician Schweinester), concluded on 03.03.14 o Start PIR data collection: 03.03.2014 o Start monitoring survey: 12.03.2014 o Start light programming: 03.09.2014 o Endline measurement: 26.02.2015
TP10	❧ Gender: male ❧ Born in: 1946 ❧ Eyesight: very good (needs glasses to read) ❧ Mobility: quite good ❧ Care Level: none ❧ Chronic diseases: cardiac insufficiency, high blood pressure, insufficient kidneys (dialysis) ❧ Activities: reading, walking, shopping ❧ General condition: mentally fit and physically limited due to dialysis ❧ Group: GL Deluxe (PIR + light) o Baseline measurement: 03.04., 10.4.2014 o Installing light system: 18.06.2014 o Start PIR data collection: 12.06.2014 o Start monitoring survey: 12.06.2014 o Start light programming: 12.08.2014 o Endline measurement: 27.02. + 30.3.2015
TP11	❧ Gender: female ❧ Born in: 1942 ❧ Eyesight: myopia, wears glasses, cataract operation on both eyes eight years ago, reading glasses before ❧ Mobility: no walking aid, but problems with spinal column, has problems during usage of the vacuum ❧ Care Level: none

	❧ Chronic diseases: thyroid (cold nodes, removed), sometimes high blood pressure ❧ Activities: reading, computer 2-3 hours ❧ General condition: good ❧ Group: PIR (no light) o Baseline measurement: 25.09., 10.10.2014 o Installing light system: no light installation o Start PIR data collection: installed during the calendar week 44 o Start monitoring survey: 01.10.2014 o Endline measurement: 09.03.2015
TP12	❧ Gender: female ❧ Born in: 1948 ❧ Eyesight: very good ❧ Mobility: quite good, but need to use a wheelchair gets with a lifting device from wheelchair into her bed ❧ Care Level: none ❧ Chronic diseases: none ❧ Activities: has twice a week physiotherapy, uses an iPad to Skype with her family, goes into the restaurant ❧ General condition: good ❧ Group: PIR (no light) o Baseline measurement: 01.07.,14.07., 21.07.2014 o Start PIR data collection: 17.06.2014 o Start monitoring survey: 15.07.2014 o Endline measurement: 19.02.2015
TP13	❧ Gender: female ❧ Born in: 1945 ❧ Eyesight: no glasses ❧ Mobility: good ❧ Care Level: none ❧ Chronic diseases: no ❧ Activities: unknow ❧ General condition: good ❧ Group: PIR (no light) o Baseline measurement: 15.05., 19.05.2014 o Start PIR data collection: 11.06.2014 o Start monitoring survey: 01.07.2014 o Endline measurement: 26.02.2015
TP14	❧ Gender: female

	❧ Born in: 1928 ❧ Eyesight: no glasses ❧ Mobility: moderate till good ❧ Care Level: none ❧ Chronic diseases: high blood pressure ❧ Activities: attendance at church, does some light gardening work ❧ General condition: moderate ❧ Group: PIR (no light) o Baseline measurement: 13.10. + 27.10.2014 o Start PIR data collection: 10.07.2014 o Start monitoring survey: 19.11.2014 o Endline measurement: 13.03. + 27.03.2015
TP15	❧ Gender: female ❧ Born in: 1925 ❧ Eyesight: needs glasses just for reading small texts ❧ Mobility: good, still rides a bicycle ❧ Care Level: none ❧ Chronic diseases: no ❧ Activities: does the household by herself, a lot underway with friends ❧ General condition: very good ❧ Group: PIR (no light) o Baseline measurement: Finished with 01.09.2014 o Start PIR data collection: 28.07.2014 o Start monitoring survey: 31.07.2014 o Endline measurement: 26.02. + 13.03.2015
TP16	❧ Gender: female ❧ Born in: 1945 ❧ Eyesight: reading glasses ❧ Mobility: good, rides a bicycle ❧ Care Level: none ❧ Chronic diseases: slight diabetes mellitus type 2 ❧ Activities: a lot underway ❧ General condition: very good ❧ Group: PIR (no light) o Baseline measurement: 07.10., 05.11.2014 o Start PIR data collection: 08.2014 o Start monitoring survey: 07.10.2014 o Endline measurement: 19.03. + 27.03.2015

TP17	❧ Gender: female ❧ Born in: 1935 ❧ Eyesight: poor (always needs glasses), cataract. ❧ Mobility: poor, needs walking frame, rollator inside the apartment, crutches outside ❧ Care Level: none ❧ Chronic diseases: high blood pressure, thyroid struma ❧ Activities: reading, watching tv, crosswords ❧ General condition: mentally fit and physically limited (difficulties to walk) ❧ Group: PIR (no light) o Baseline measurement: 03.04., 8.04., 10.4.2014 o Start PIR data collection: 16.6.2014 o Start monitoring survey: 19.06.2014 o Endline measurement: 24.02. + 04.03.2015
TP18	❧ Gender: female ❧ Born in: 1944 ❧ Eyesight: good (high sensibility due to eye operation) ❧ Mobility: good ❧ Care Level: none ❧ Chronic diseases: none ❧ Activities: reading, walking, shopping ❧ General condition: mentally and physically fit ❧ Group: GL Deluxe (PIR + light) o Baseline measurement: 07.04.2014 o Installing light system: 25.07.2014 o Start PIR data collection: 13.06.2014 o Start monitoring survey: 13.06.2014 o Start light programming: 28.08.2014 o Endline measurement: 25.02. + 04.03.2015
TP19	❧ Gender: female ❧ Born in: 1935 ❧ Eyesight: good (needs glasses only to read) ❧ Mobility: good ❧ Care Level: none ❧ Chronic diseases: osteoporosis ❧ Activities: voluntary services, reading, shopping ❧ General condition: mentally and physically fit ❧ Social contacts in the apartment: twice a week contacts with friends and relatives

	❧ Group: PIR (no light) o Baseline measurement: 06.05. + 07.05.2015 o Start PIR data collection: 18.06.2014 o Start monitoring survey: 18.06.2014 o Endline measurement: 24. + 26.02.2015

Annex III: Project Fact Sheet

Name of the project, acronym, number:

Ambient Light Guiding System for the Mobility Support of Elderly People, Guiding Light, AAL-2011-4-033

Coordinator Organization:

University of Applied Sciences Vorarlberg (A)

Length of the project and starting date:

36 month, May 1, 2012 – April 30, 2015

Partners:

Name	Type	Country	Web address
Fachhochschule Vorarlberg	R&D	Austria	www.fhv.at
Tridonic GmbH & Co KG	SME	Austria	www.tridonic.com
Bartenbach GmbH	SME	Austria	www.bartenbach.com
myVitali AG	SME	Switzerland	www.myvitali.com
apollis - Institut für Sozialforschung und Demoskopie O.H.G	SME	Italy	www.apollis.it
YOUSE GmbH	SME	Germany	www.youse.de

Objective of the project (<u>Between 400 and 500 characters</u>):

Within this project we will develop and implement an intelligent light wayguidance system, which should attenuate age-related mobility impairments caused by reduced spatio-temporal orientation, worry about getting lost, and fear of falling. This guiding light will consist of up to date lighting technologies, innovative intelligent control algorithms, smart mobility monitoring systems, and a distributed information system for mobility parameters. Together with end-users and all stakeholders we will examine how these components can be combined with inter-personal care services.

Abstract of the project (Including technology in use, end-users involvement – <u>between 1200 and 1500 characters):</u>

Light is used to meet visual needs of human (e.g. highlighting risks of falling), is applied for temporal orientation throughout the day (e.g. emphasizing day-night rhythm), for spatial navigation during activities of daily living (e.g. illumination of a defined location areas) and is used as remembering as well as information signal (e.g. light spots and light signals). Light therefore has great potential for attenuation of age-related mobility impairments caused by reduced spatio-temporal orientation, worry about getting lost, and fear of falling.

To make use of light in this sense, we will implement a light wayguidance system in private homes of older people that performs a time- and motion-controlled change of intensity and color temperature of room lightings. We will use existing lightings in these rooms and supplement them with additional lighting equipment and electrical installation technologies. After modification light characteristics of lamps will change automatically according to the personal daily routine of residents.

This, however, will not be a rigid system. At the same time mobility parameters of the residents will be monitored (such as movements in and outside the home) and the results of analyzing these data will be used to change the programming of light variations. The adjustment of light programming will be done automatically, nevertheless, residents can manually readjust their lights at any time.

The degree of mobility is an important indicator of health. For this reason we will integrate relevant parameters into a distributed information system as the basis for decisions about preventive provisions. This will give residents at any time insight into their health status, which can be shared with persons of trust (e.g. relatives, doctor).

Expected results and impact (<u>Between 400 and 500 characters</u>):

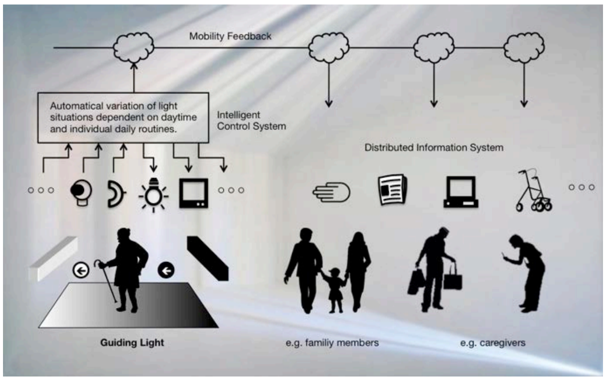
Outcome of the project is an intelligent light wayguidance system consisting a variable set of flexible modules that work together with other heterogeneous home automation systems, information and communication systems as seamlessly as possible. The application of this guiding light system will support the spatial-temporal orientation of older people and thus sustain their mobility as long as possible.

Total cost of project and public contribution:

tbd

Images or graphic (Logo, images or photos showing the product or service):

Images or photographs (also graphics where needed) are mandatory. Send ftp link or esp file.



Website link(s):

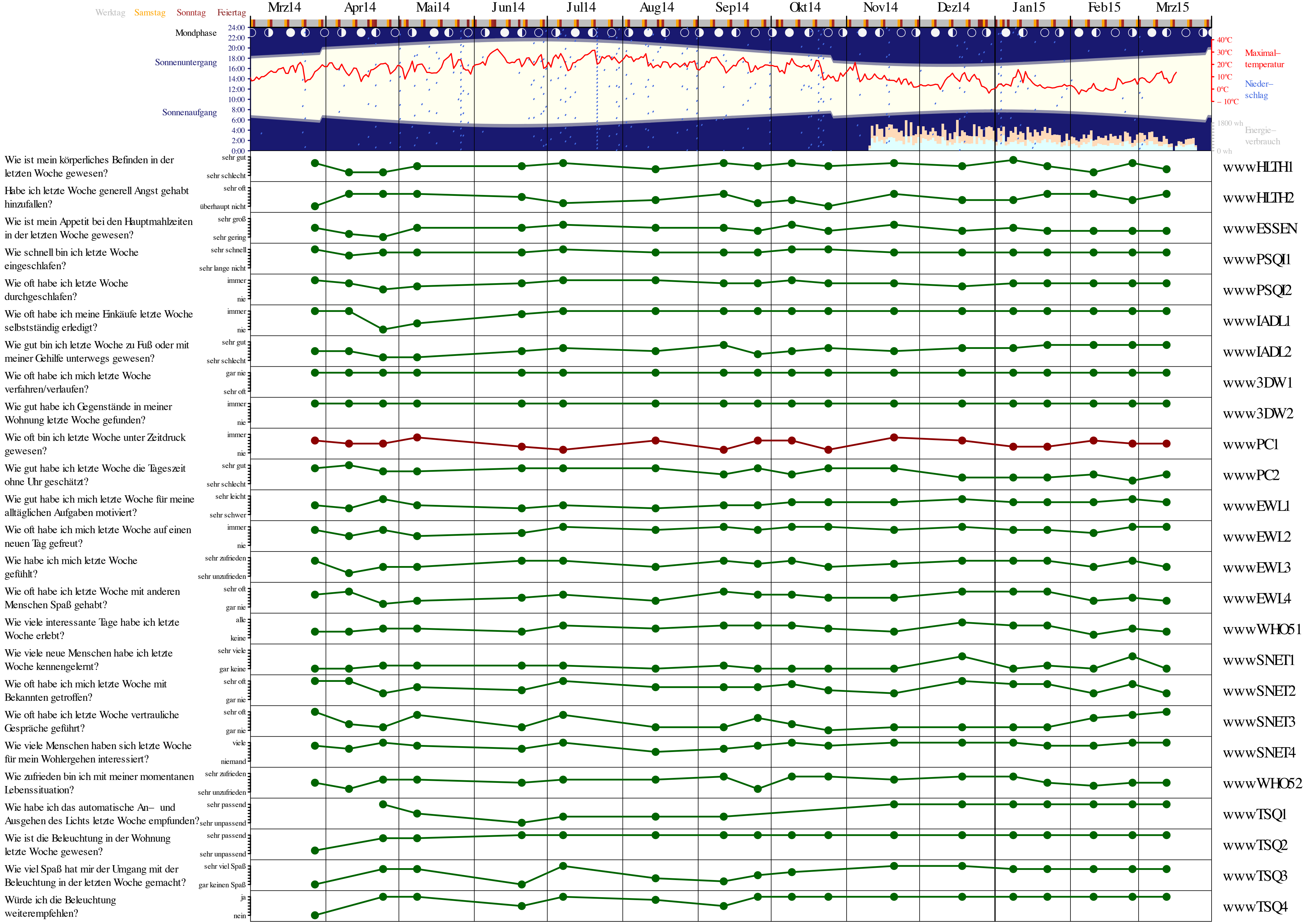
guiding-light.labs.fhv.at

Contact person (name, e-mail, phone, address):

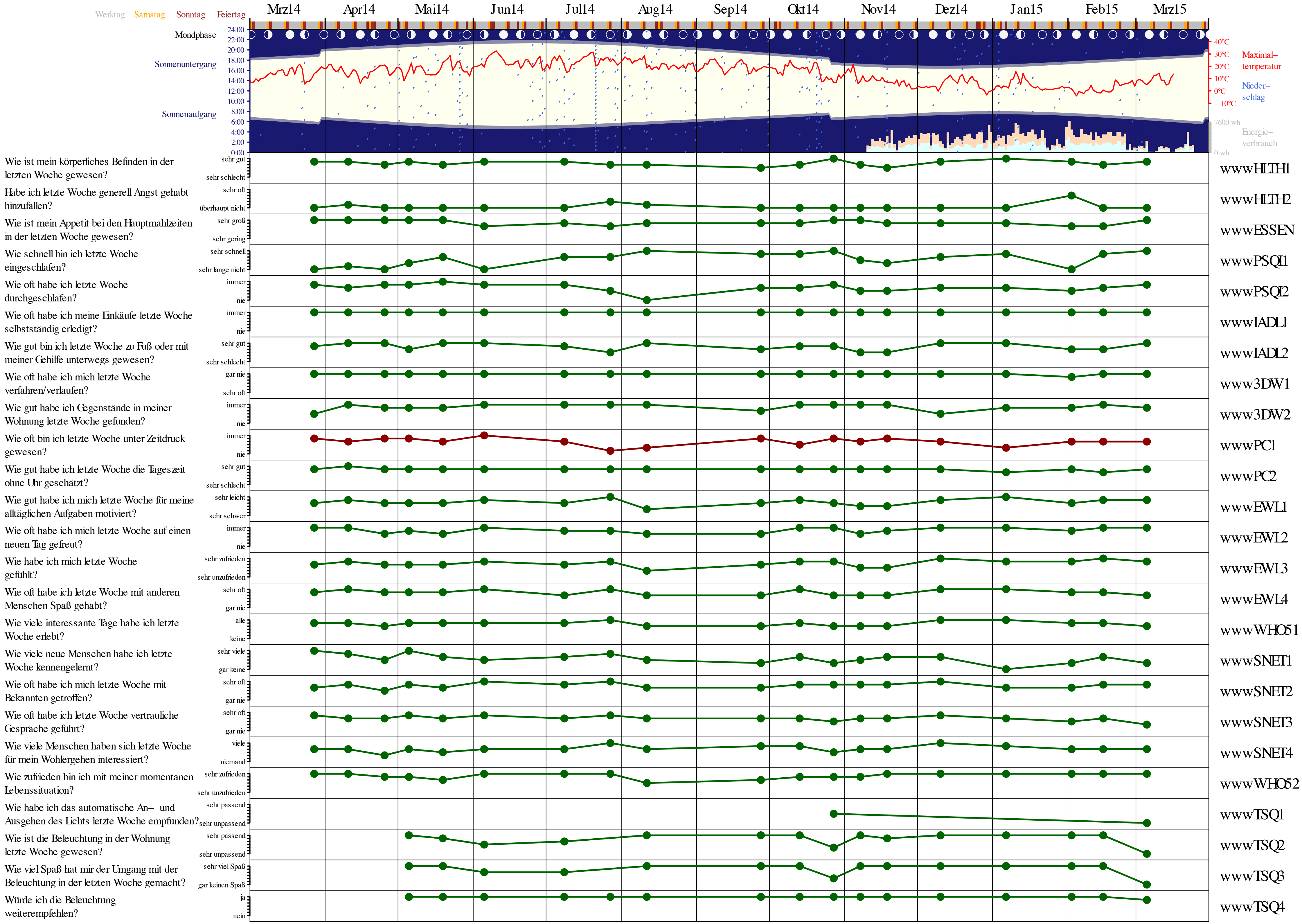
Prof. Dr. Guido Kempter, guido.kempter@fhv.at, +43 5572 792 7300, Fachhochschule Vorarlberg, Hochschulstrasse 1, A-6850 Dornbirn

Annex IV: Trial condition for all test persons

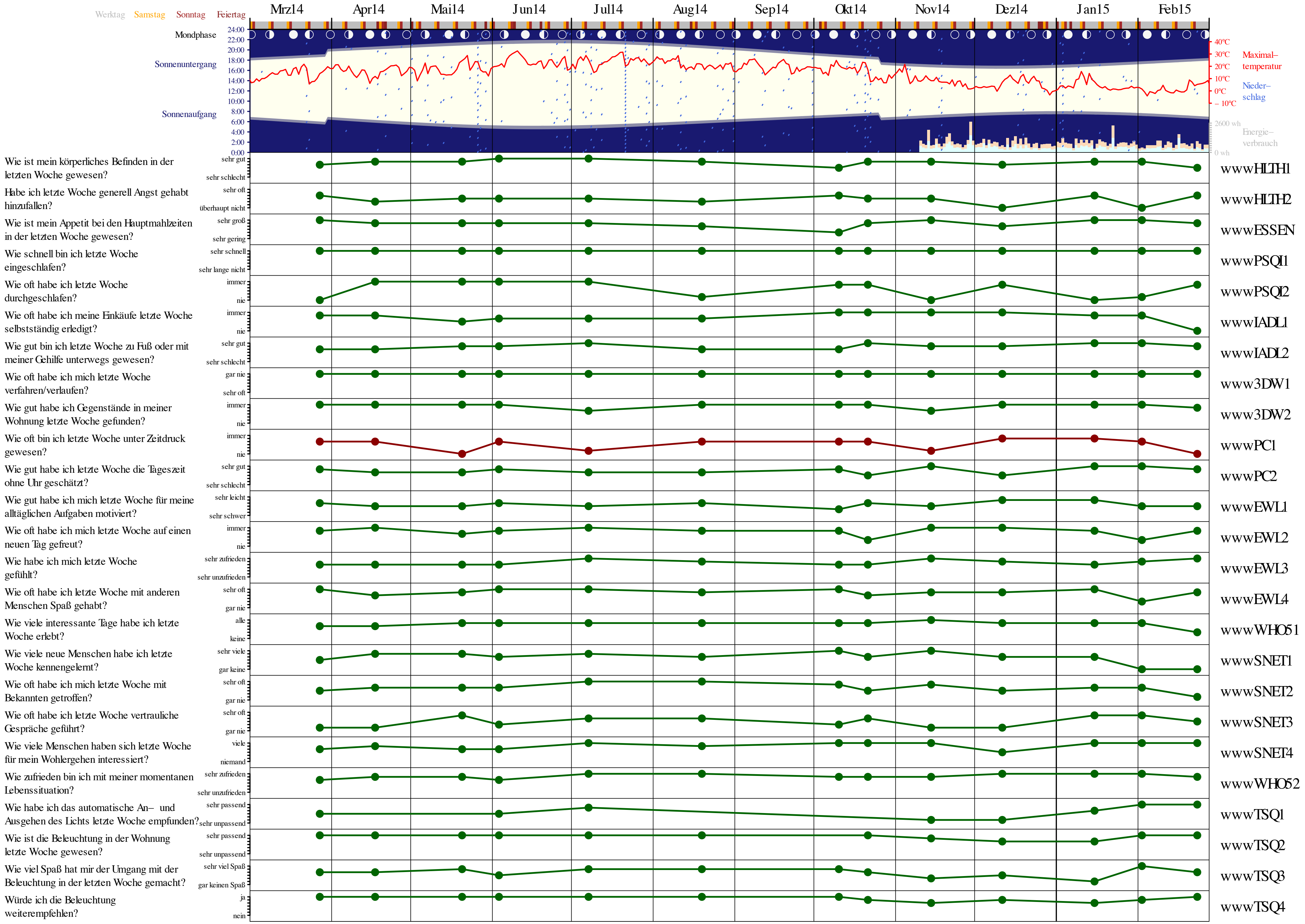
VP 1 (YOUSE): GL+ PIR, w, 1928, Vaterstetten



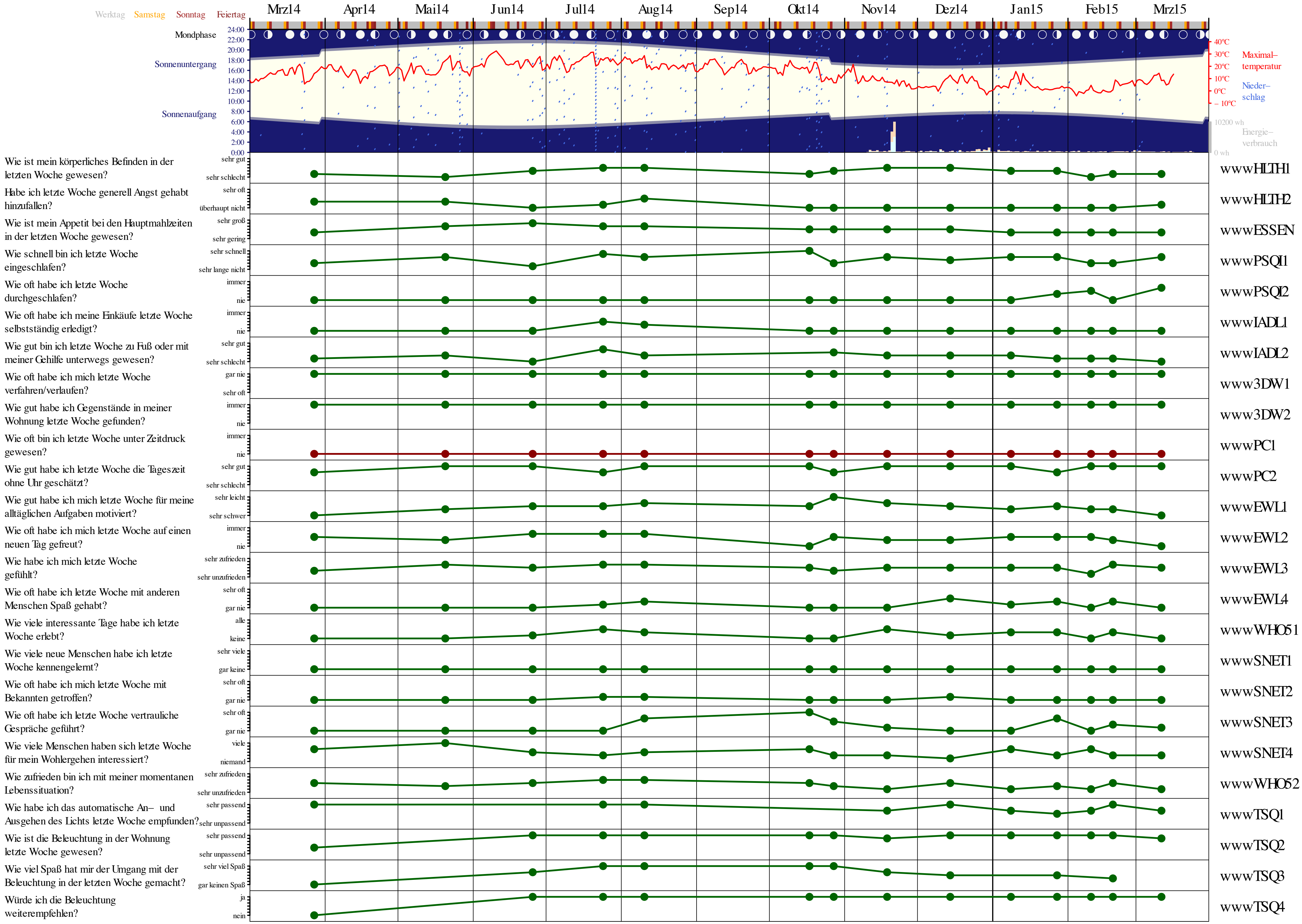
VP 2 (YOUSE): GL+ PIR, w, 1934, Vaterstetten



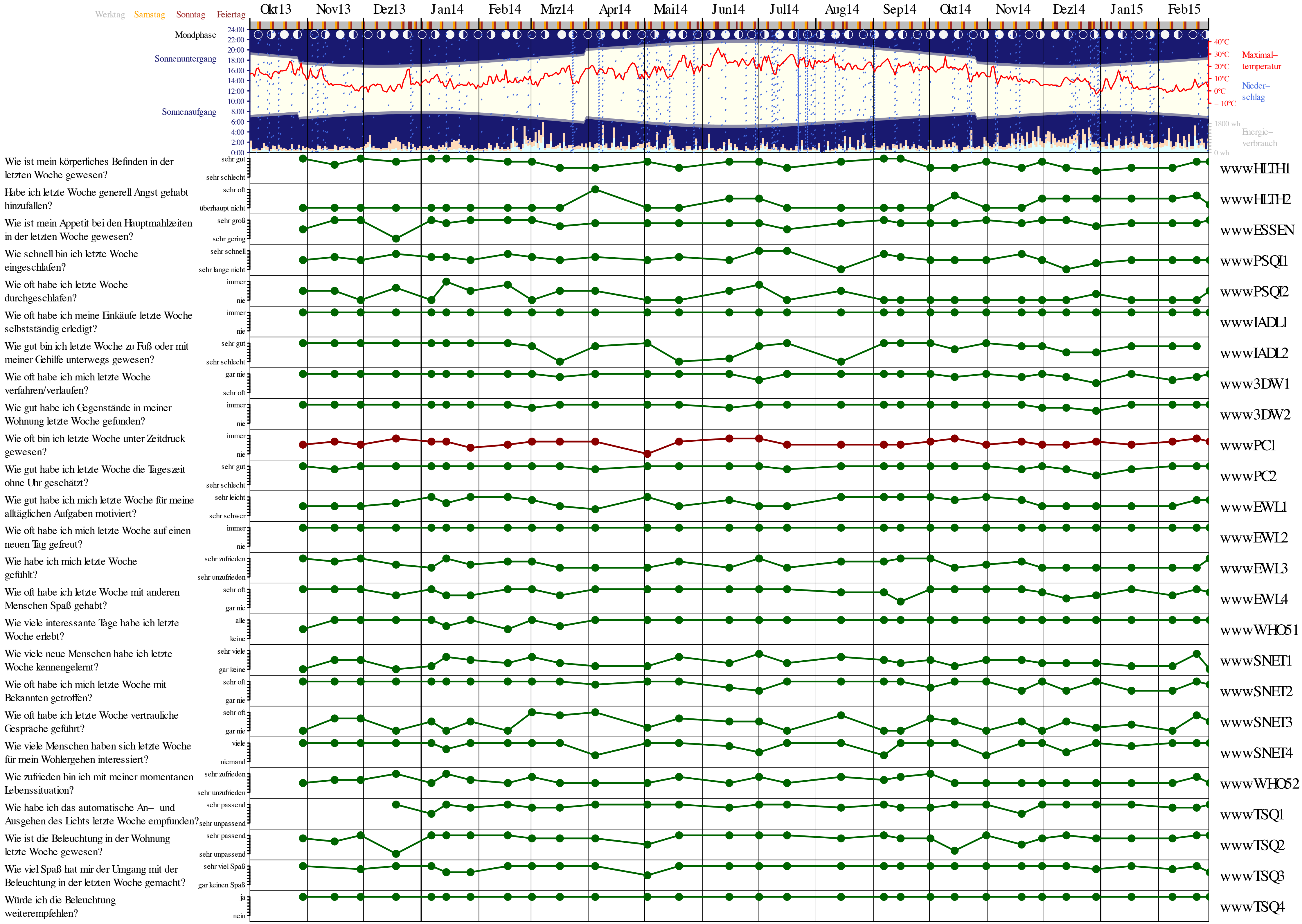
VP 3 (YOUSE): GL+ PIR, w, 1935, Vaterstetten



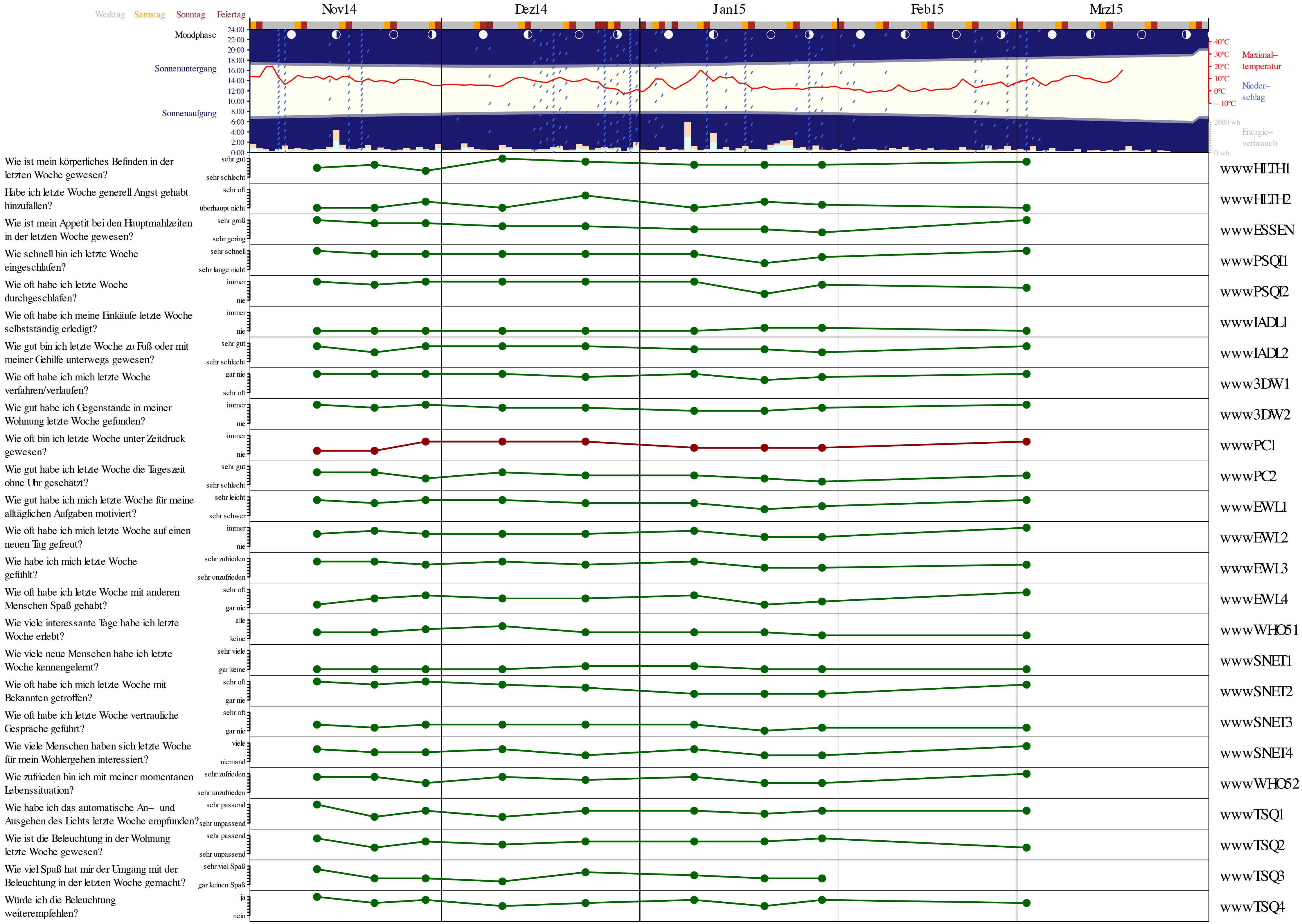
VP 4 (YOUSE): GL+ PIR, w, 1946, Wolfratshausen



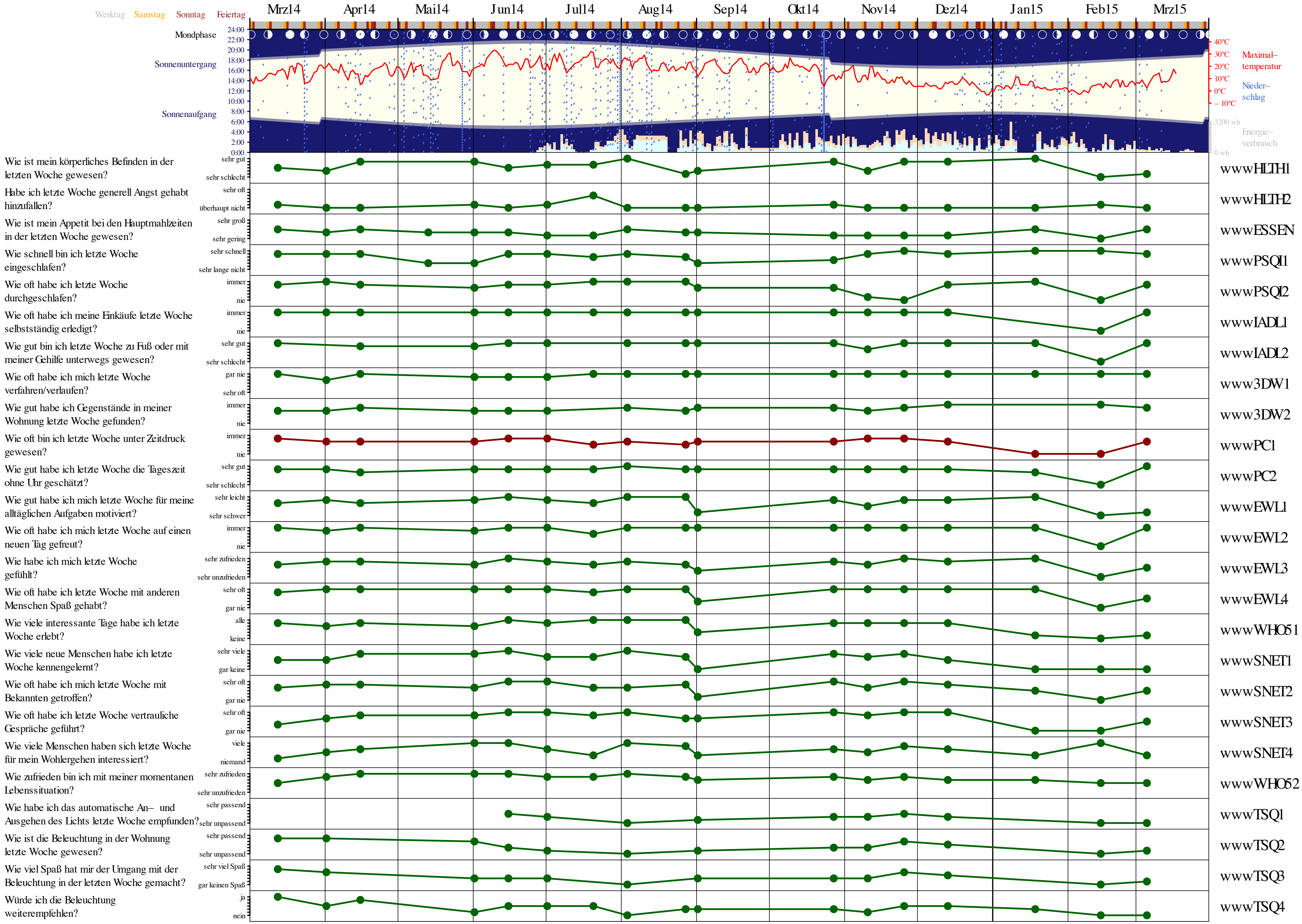
VP 5 (FHV): GL+ PIR, w, 1928, Götzis



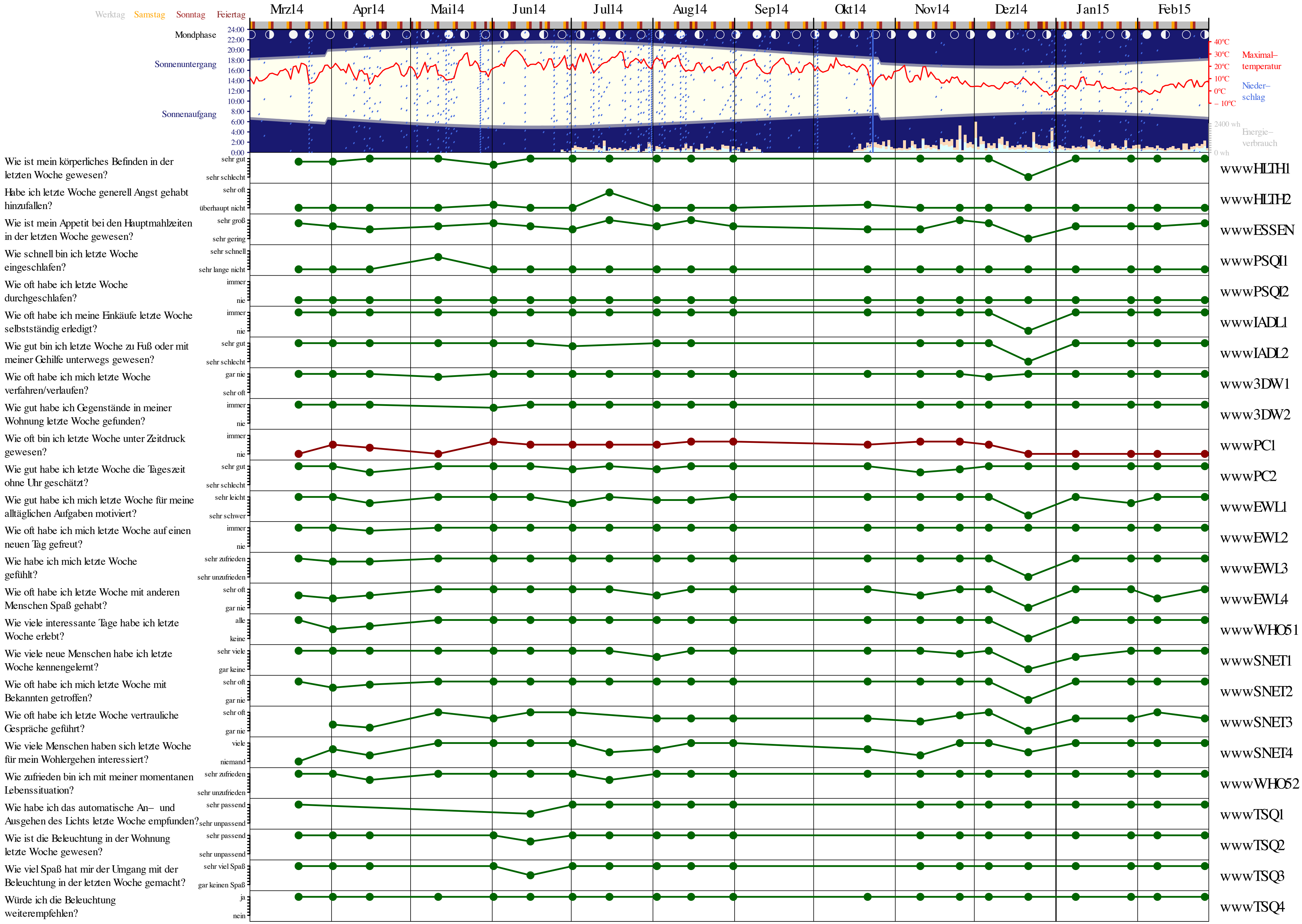
VP 6 (FHV): GL+ PIR, m, 1949, Götzis



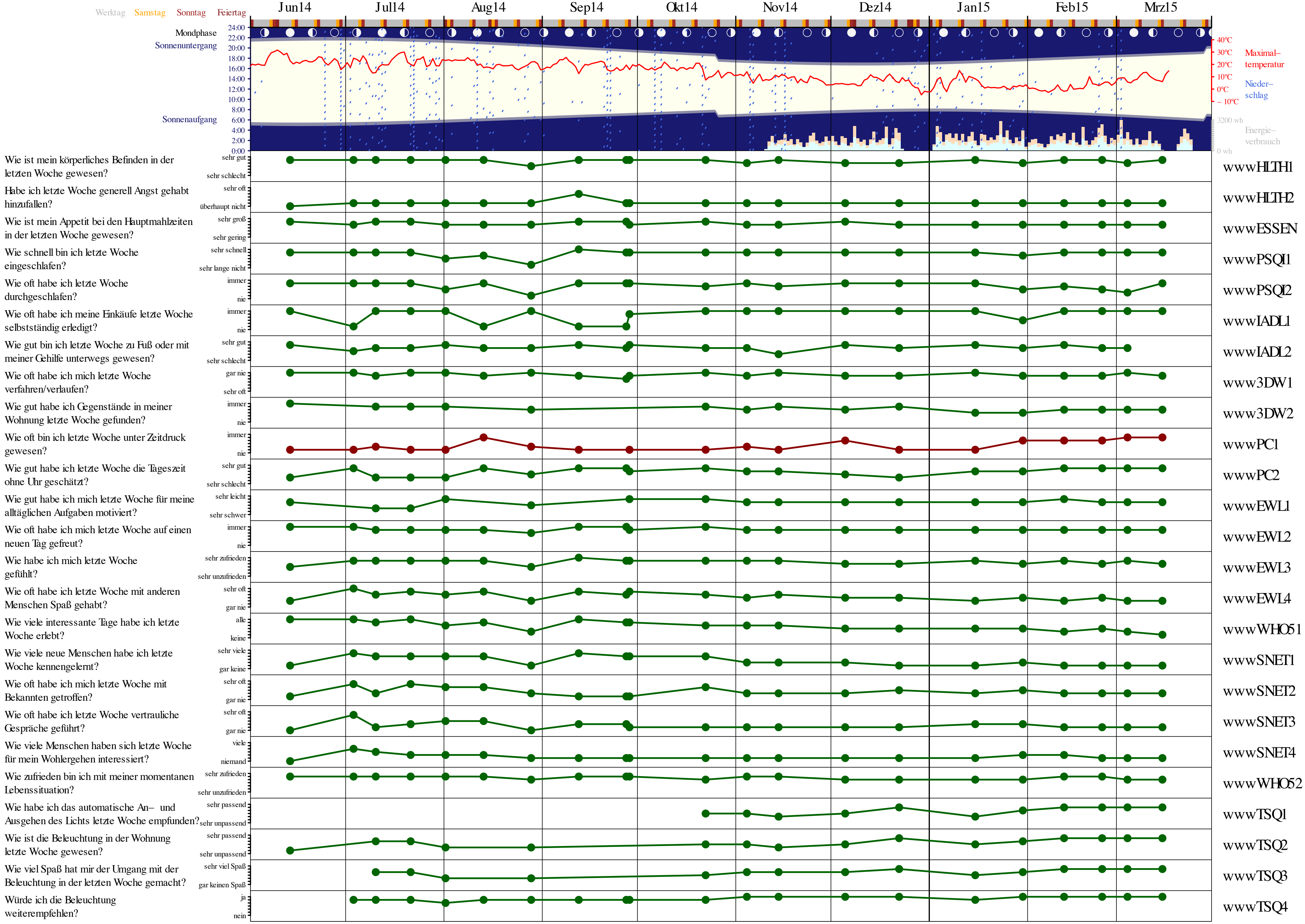
VP 7 (BLL): GL+ PIR, w, 1949, Wörgl



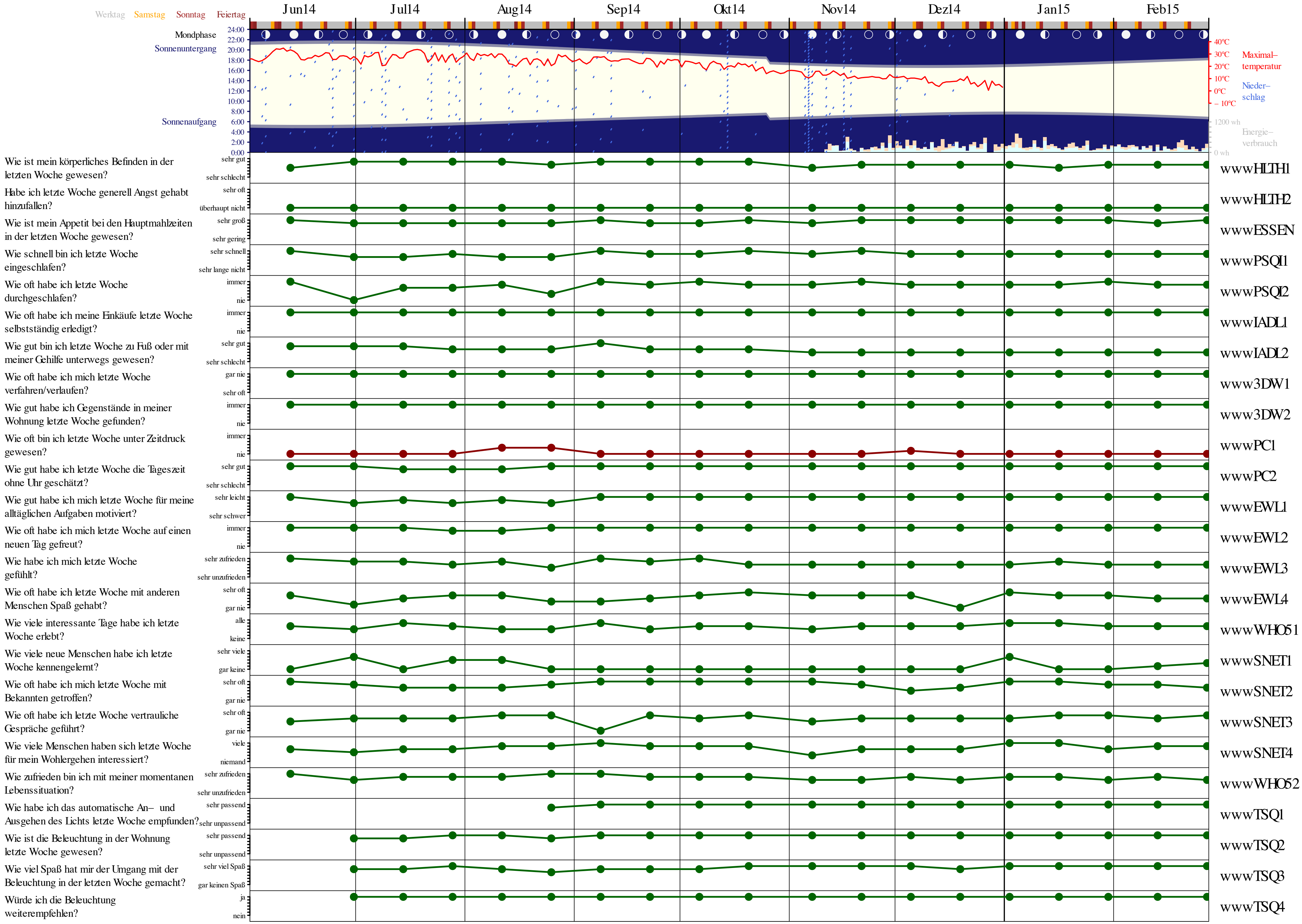
VP 8 (BLL): GL+ PIR, w, 1946, Wörgl



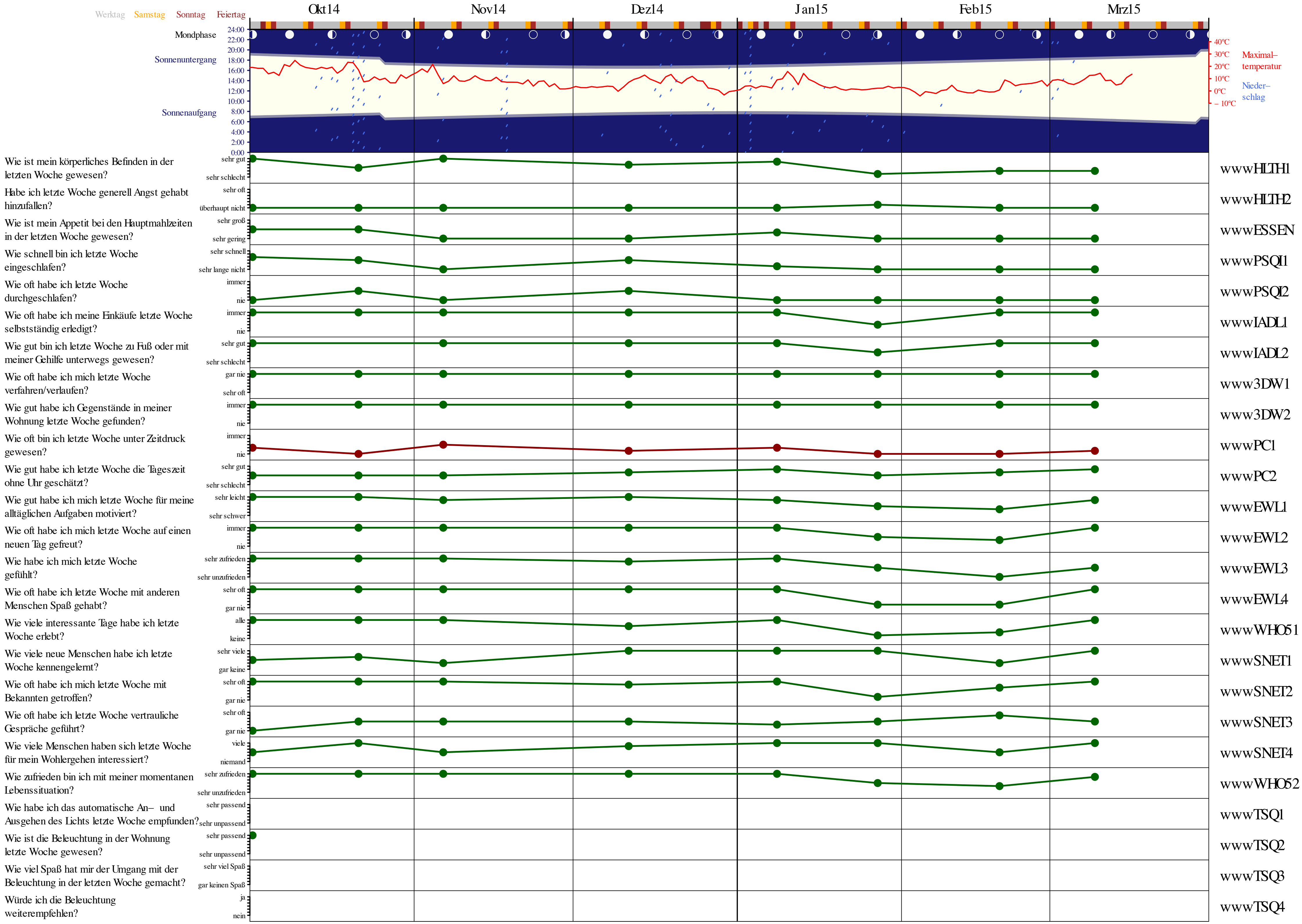
VP 9 (MVA): GL+ PIR, w, 1949, Zürich



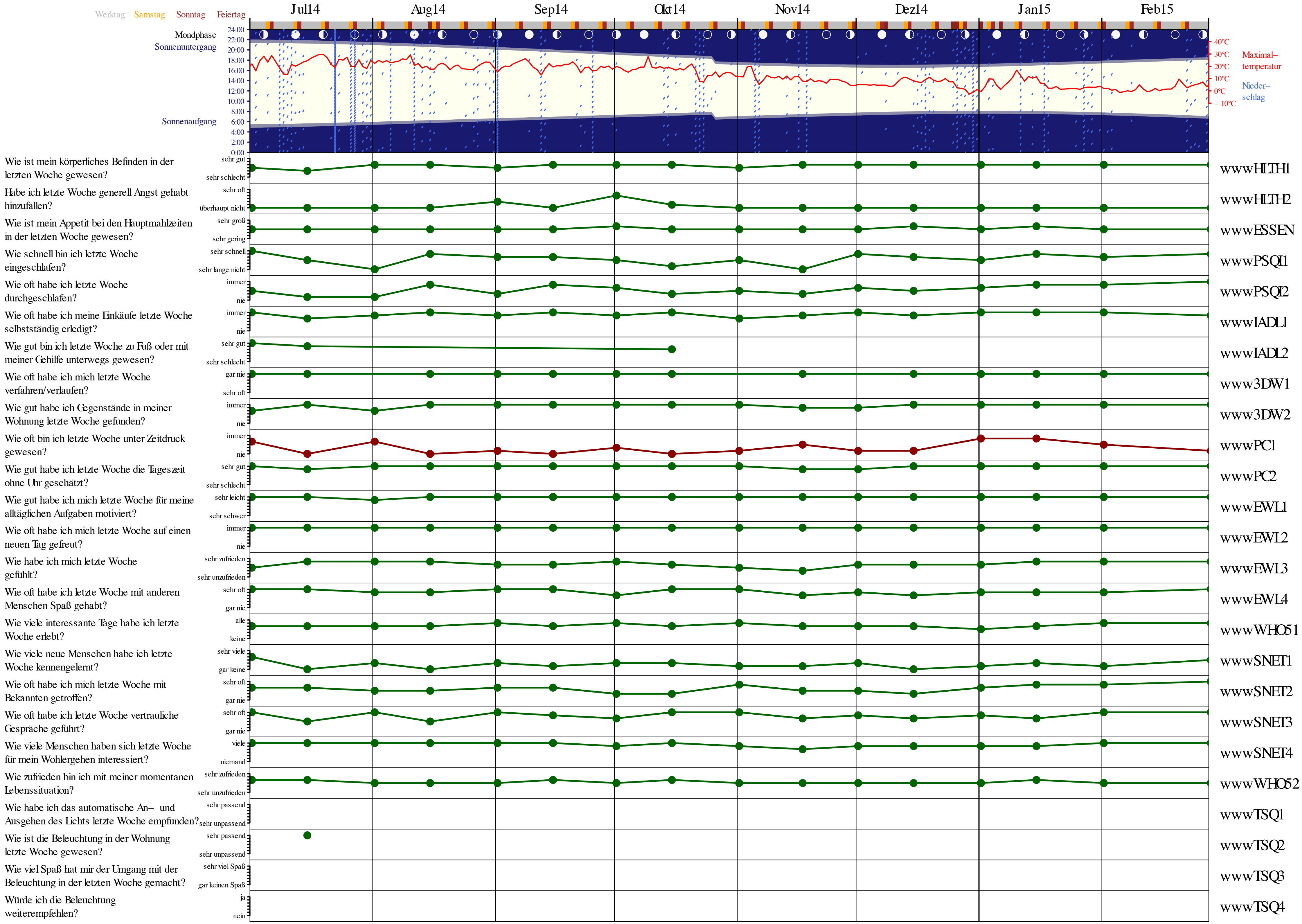
VP 10 (APOLLIS): GL+ PIR, m, 1946, Neumarkt



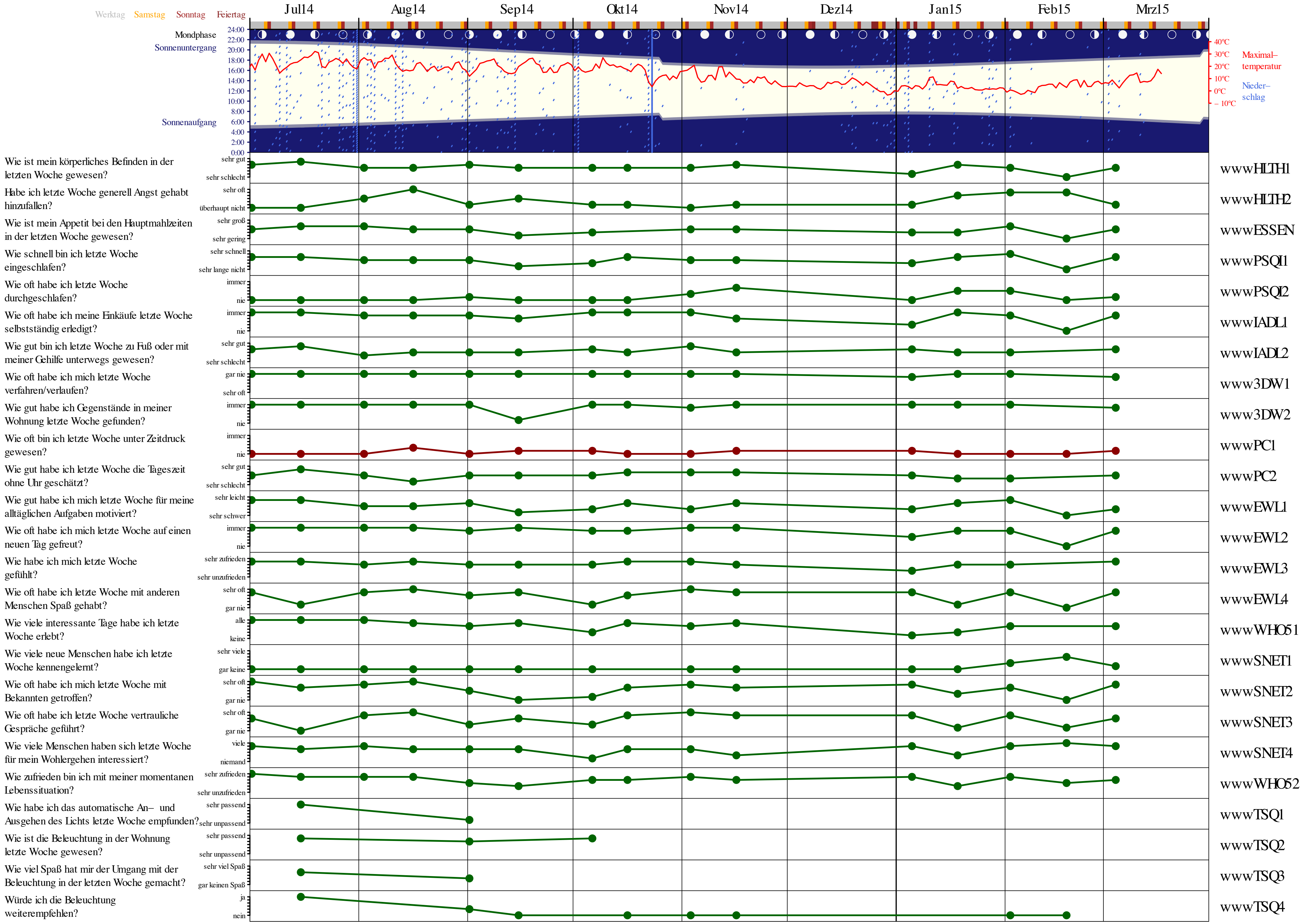
VP 11 (YOUSE): nur PIR, w, 1942, Vaterstetten



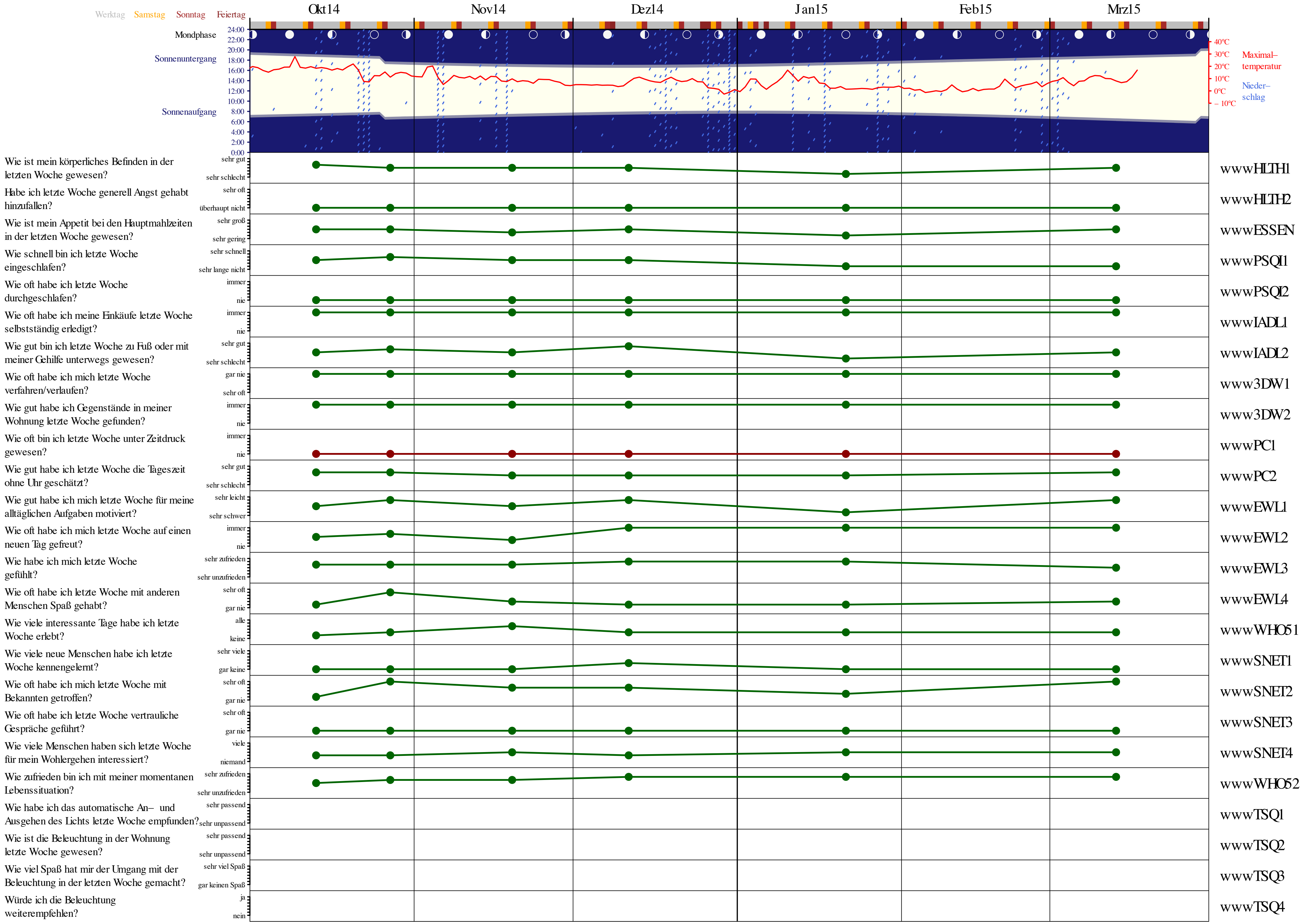
VP 12 (FHV): nur PIR, w, NA, Götzis



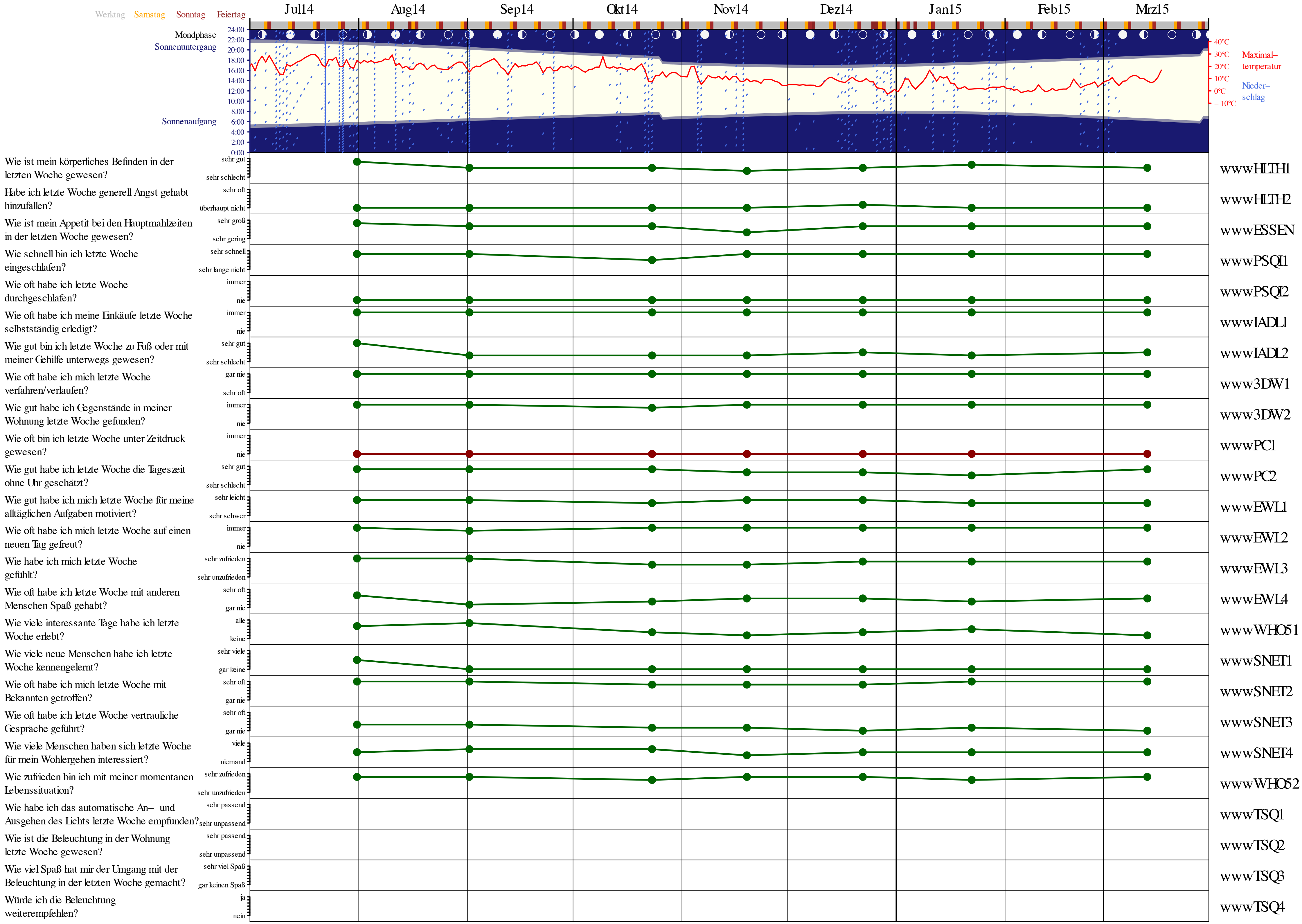
VP 13 (BB): nur PIR, w, 1945, Wörgl



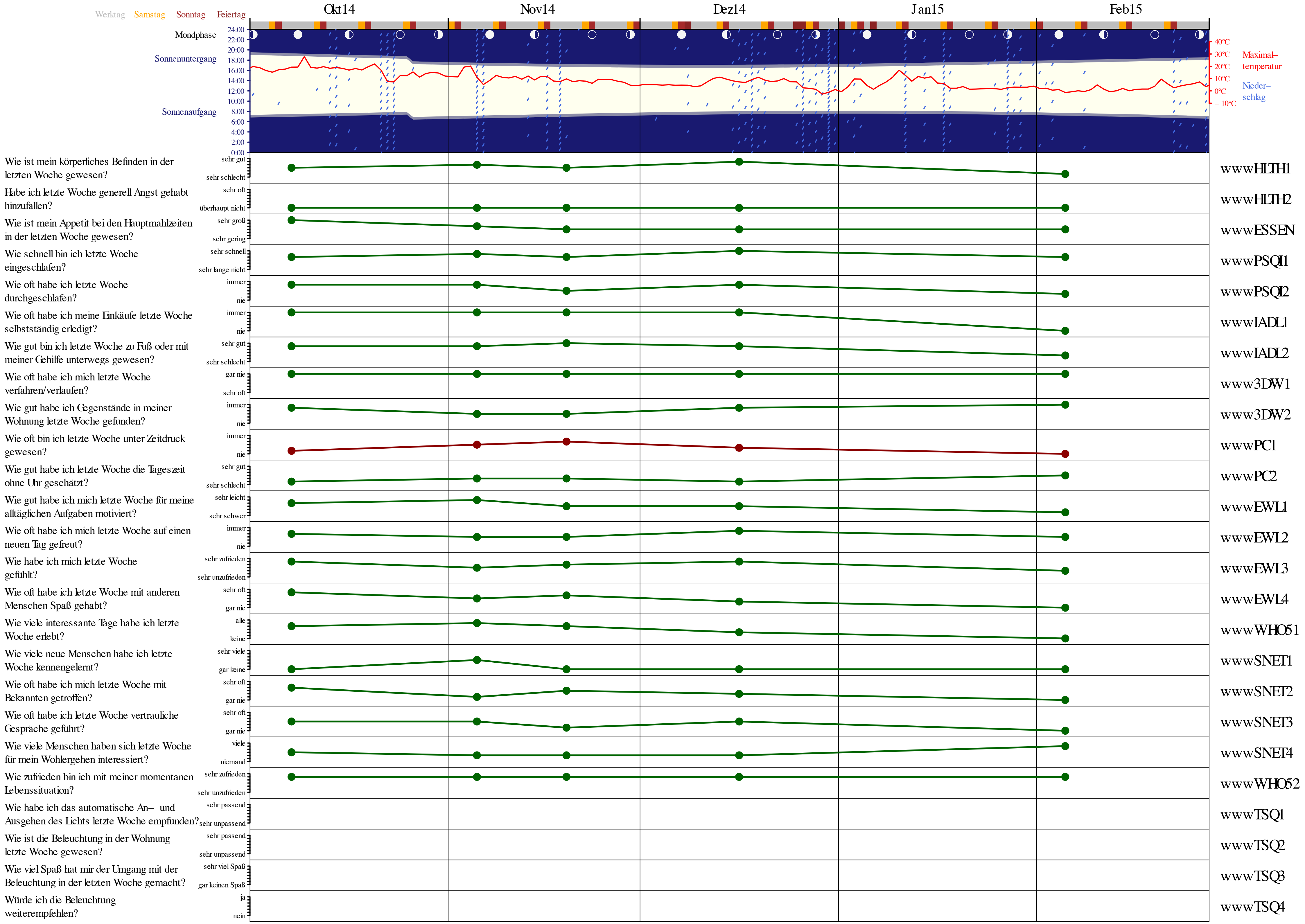
VP 14 (MVA): nur PIR, w, 1928, Hard



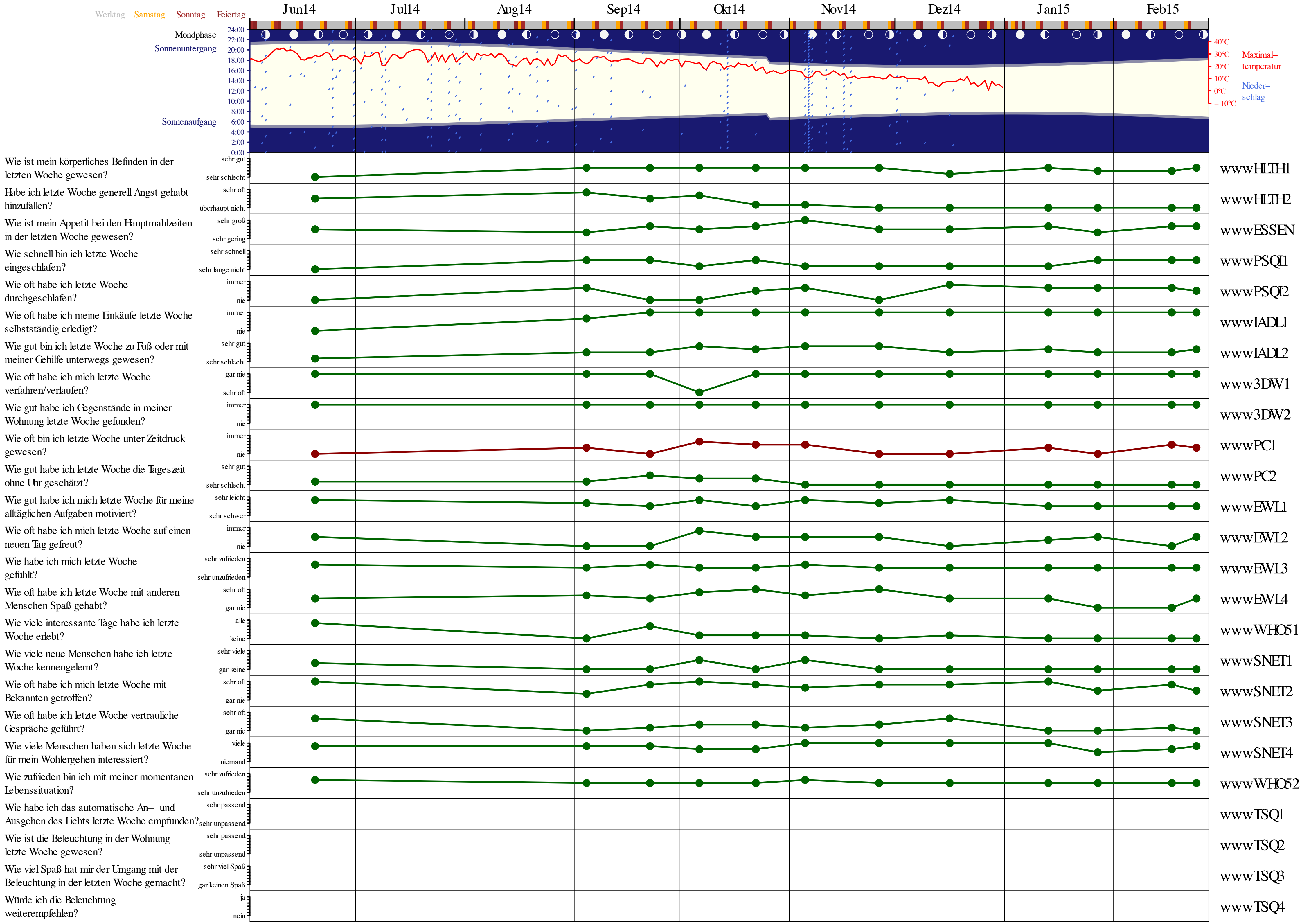
VP 15 (MVA): nur PIR, w, 1925, Hard

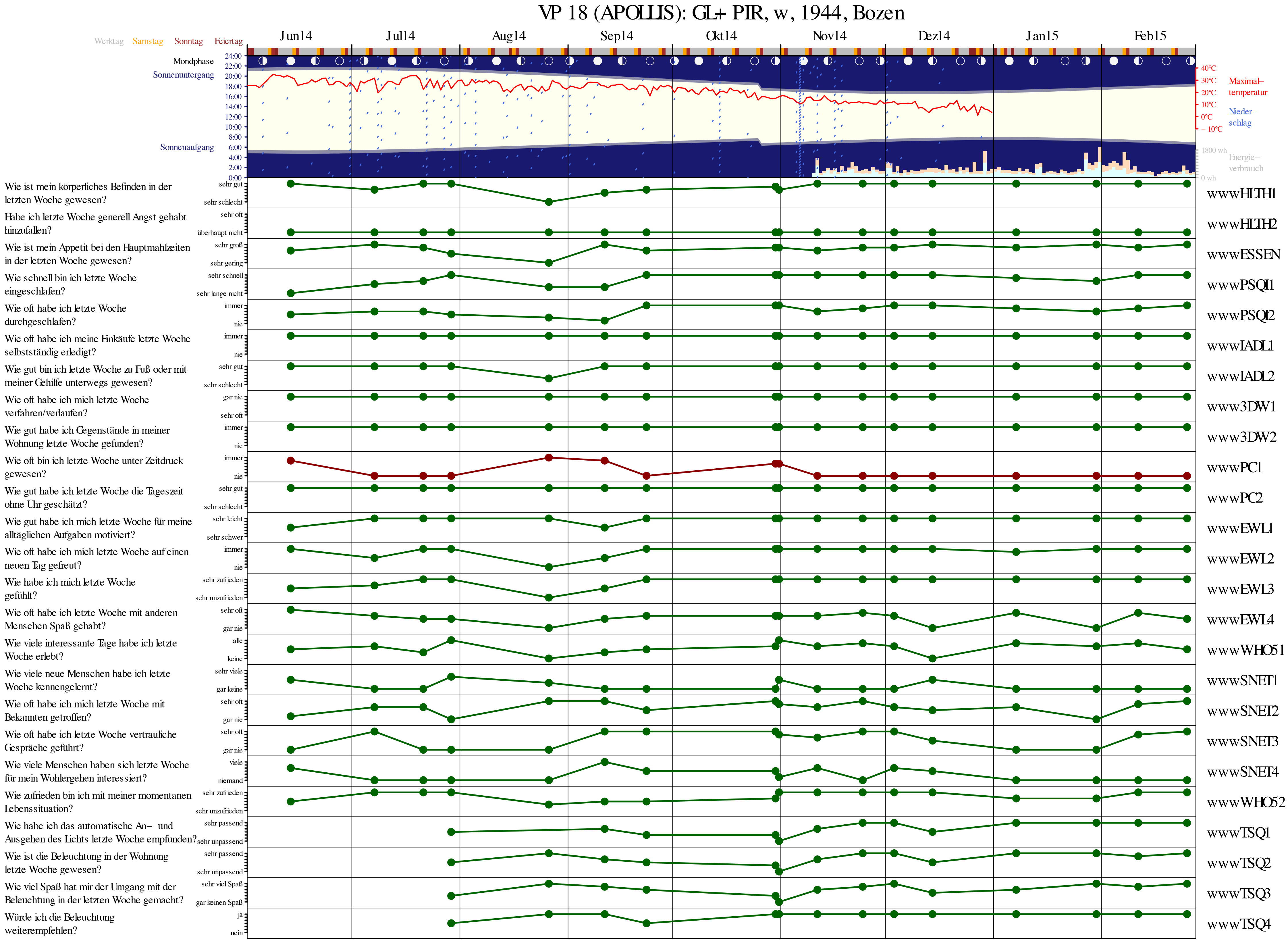


VP 16 (MVA): nur PIR, w, 1945, Hard

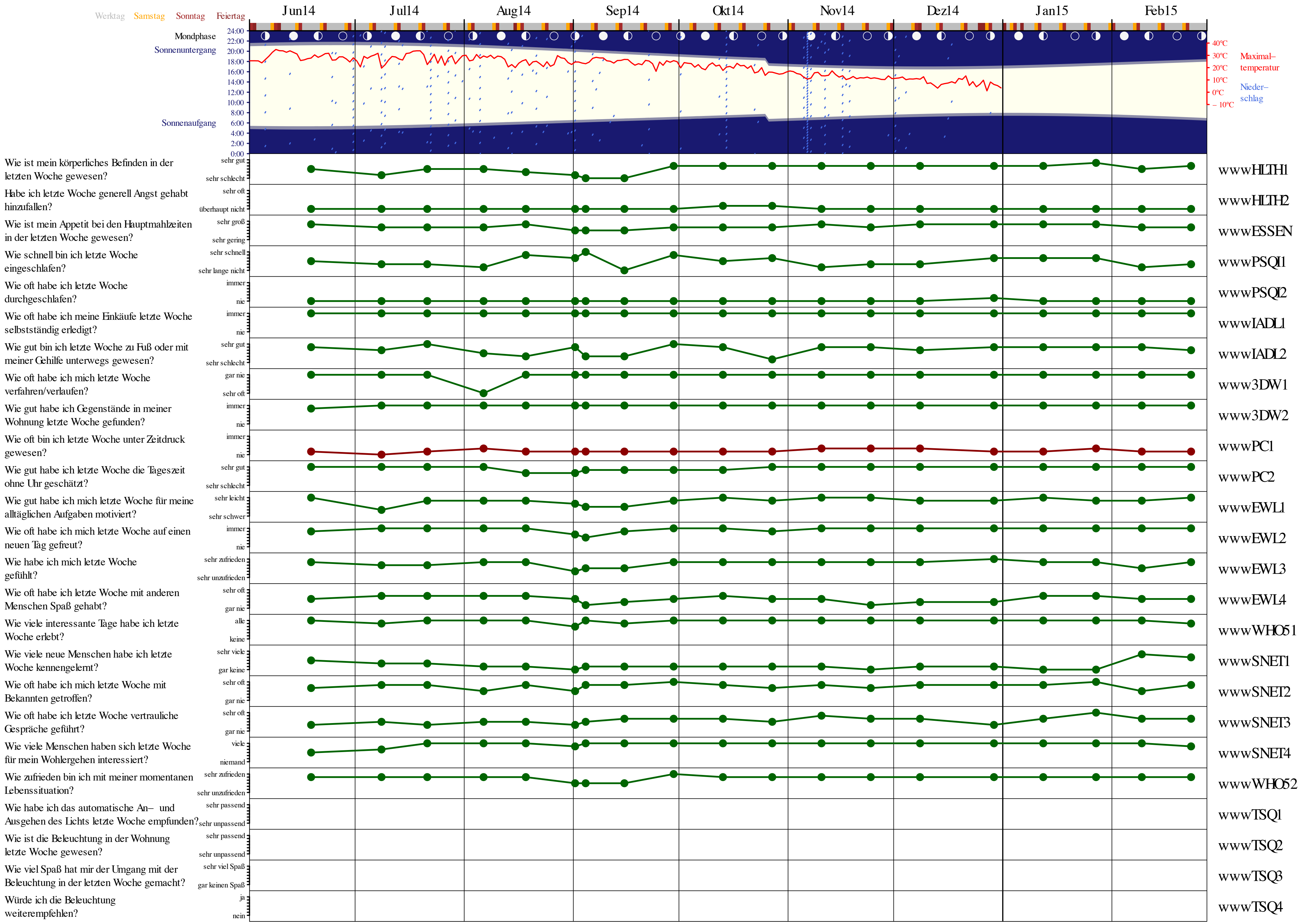


VP 17 (APOLLIS): nur PIR, w, 1935, Neumarkt




VP 18 (APOLLIS): GL+ PIR, w, 1944, Bozen
Werktag
Samstag
Sonntag
Feiertag
Jun14
Jul14
Aug14
Sep14
Okt14
Nov14
Dez14
Jan15
Feb15
Mondphase
Sonnenuntergang
Sonnenaufgang
Maximal–temperatur
Nieder–schlag
Energie–verbrauch
Wie ist mein körperliches Befinden in der letzten Woche gewesen?
sehr gut
sehr schlecht
wwwHLTH1
Habe ich letzte Woche generell Angst gehabt hinzufallen?
sehr oft
überhaupt nicht
wwwHLTH2
Wie ist mein Appetit bei den Hauptmahlzeiten in der letzten Woche gewesen?
sehr groß
sehr gering
wwwESSEN
Wie schnell bin ich letzte Woche eingeschlafen?
sehr schnell
sehr lange nicht
wwwPSQI1
Wie oft habe ich letzte Woche durchgeschlafen?
immer
nie
wwwPSQI2
Wie oft habe ich meine Einkäufe letzte Woche selbstständig erledigt?
immer
nie
wwwIADL1
Wie gut bin ich letzte Woche zu Fuß oder mit meiner Gehilfe unterwegs gewesen?
sehr gut
sehr schlecht
wwwIADL2
Wie oft habe ich mich letzte Woche verfahren/verlaufen?
gar nie
sehr oft
www3DW1
Wie gut habe ich Gegenstände in meiner Wohnung letzte Woche gefunden?
immer
nie
www3DW2
Wie oft bin ich letzte Woche unter Zeitdruck gewesen?
immer
nie
wwwPC1
Wie gut habe ich letzte Woche die Tageszeit ohne Uhr geschätzt?
sehr gut
sehr schlecht
wwwPC2
Wie gut habe ich mich letzte Woche für meine alltäglichen Aufgaben motiviert?
sehr leicht
sehr schwer
wwwEWL1
Wie oft habe ich mich letzte Woche auf einen neuen Tag gefreut?
immer
nie
wwwEWL2
Wie habe ich mich letzte Woche gefühlt?
sehr zufrieden
sehr unzufrieden
wwwEWL3
Wie oft habe ich letzte Woche mit anderen Menschen Spaß gehabt?
sehr oft
gar nie
wwwEWL4
Wie viele interessante Tage habe ich letzte Woche erlebt?
alle
keine
wwwWHO51
Wie viele neue Menschen habe ich letzte Woche kennengelernt?
sehr viele
gar keine
wwwSNET1
Wie oft habe ich mich letzte Woche mit Bekannten getroffen?
sehr oft
gar nie
wwwSNET2
Wie oft habe ich letzte Woche vertrauliche Gespräche geführt?
sehr oft
gar nie
wwwSNET3
Wie viele Menschen haben sich letzte Woche für mein Wohlergehen interessiert?
viele
niemand
wwwSNET4
Wie zufrieden bin ich mit meiner momentanen Lebenssituation?
sehr zufrieden
sehr unzufrieden
wwwWHO52
Wie habe ich das automatische An– und Ausgehen des Lichts letzte Woche empfunden?
sehr passend
sehr unpassend
wwwTSQ1
Wie ist die Beleuchtung in der Wohnung letzte Woche gewesen?
sehr passend
sehr unpassend
wwwTSQ2
Wie viel Spaß hat mir der Umgang mit der Beleuchtung in der letzten Woche gemacht?
sehr viel Spaß
gar keinen Spaß
wwwTSQ3
Würde ich die Beleuchtung weiterempfehlen?
ja
nein
wwwTSQ4

VP 19 (APOLLIS): nur PIR, w, 1935, Bozen



VP 62 (FHV): GL+ PIR, m, 1933, Götzis