Ambient Lighting Assistance for an Ageing Population

Specific Targeted Research Project

Final Activity Report

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PRELIMINARY REMARKS

The Final Report covers the whole duration of the ALADIN project and cumulates and summarises the project activities and results over the full duration. Since it is meant for direct publication by the Commission, it has to be broadly comprehensible to an interested general reader. Therefore it avoids technical jargon as well as EU-specific administrative terminology. It describes the work performed and the results achieved not according to work packages, but in a logical and easy to understand way.

Nonetheless, it includes all the points required by the reporting guidelines for FP6 projects, i.e. a brief description of project objectives, contractors involved, work performed and end results. It presents the methodology and approach employed and relates the achievements to the state-of-the art. It discusses to which extent the original objectives have been achieved, the problems encountered and how they have been solved. Besides, it briefly explains the impact of the project on the relevant industries and research fields and how the knowledge and the insights gained in the course of the project have been and will be disseminated and exploited including possible extensions to enhance the marketability of the ALADIN system. These aspects, however, are discussed in more detail in the Final Plan for Using and Disseminating Knowledge (Del. 5.1), which is also publicly accessible on http://www.ambient-lighting.eu.

Those interested in learning more about certain aspects of the ALADIN project, please refer to the documents published on the website. For example, if you are interested in a description of the technological system (System Description) or want to read about the findings of the empirical research to ascertain the user requirements (D1.1) or the results from both the lab and the field tests (D4.1) in more detail, you find the relevant documentation on our website: http://www.ambient-lighting.eu.

If you have any other queries, do not hesitate to contact us.

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Publishable Final Report - Executive Summary

Project objectives and innovative aspects

The overall aim of the assistive lighting system developed by ALADIN (Ambient Lighting Assistance for an Ageing Population) was to extend our knowledge about the impact of lighting on the wellbeing and comfort of older people and translate this into a cost-effective open solution. The project started in January 2007 and ended in March 2009, three months later than originally planned due to the enormous amount of data from the field trials to be analysed. But except for minor deviations from the original work plan, the project kept on track and produced a prototype of an ambient assistive lighting system which goes well beyond the state-of-the art of assistive systems for older adults.

Adaptive lighting can contribute considerably to sound sleep and a regular sleep-wake cycle, which are essential to preserve and enhance people's comfort and wellbeing. It can thus assist older adults in living at home autonomously for a longer time and contribute to their quality of life. The ALADIN prototype achieves this objective with the help of a lighting system that adapts itself continuously in accordance with an individual's biosignals and specific situations.

The ALADIN prototype is the first technology with adaptive lighting that aims to enhance people's well-being, cognitive performance and relaxation ability as well as improving their sleep quality. These aims have been realised by a combination of innovative technological solutions from lighting technology, smart sensor technology and computer- and information technologies. The prototype has been tested and applied in extensive lab tests and real-life settings.

How does it go beyond the state-of-the-art ?

So called 'ambient lighting' with varying colour, temperature and brightness has been in use for some time. However, the user has no possibility to interact with the predefined control strategy (mostly defined by the time of the day) and the lighting solutions do not take into account individual differences. In our project, we wanted to develop an approach that advances beyond the present state-of-the art, namely an intelligent control system that is capable of

capturing and analysing the individual and situational differences of the psycho-physiological effects of lighting, and

enabling the users to make adaptations tailored to their specific needs and wishes.

Current lighting solutions are not user-specific nor are they able to react to different affective states of users or situations, which is why ALADIN represents a significant advance in the progress of lighting technology.

To appreciate the innovation of the project, it is also useful to keep Pollack`s (2005) classification in mind that has been developed for describing the different types of assistive systems designed to support older adults:

Assurance systems aim primarily at ensuring safety and well-being and at reducing caregiver burden, by tracking an elder's behaviour and providing up-to-date status reports; e.g. motion and position sensors.

Compensation systems provide guidance to elderly individuals as they carry out their daily activities, reminding them of what kind of training or exercises they need to do and how to do them; e.g. alarm-clocks for the intake of pharmaceuticals.

Assessment systems attempt to infer how well a person is doing health-wise, for example by assessing what his or her cognitive level of functioning is, based on continual observation of his or her performance or monitoring of routine activities. These technologies are embraced by the term “AAL technologies”.

Whereas assurance systems are already available as commercial products, compensation systems that actually intervene and assist elderly individuals in accomplishing their daily activities mainly exist as research prototypes. However, the research challenges according to Pollack can be found primarily in the development of assessment systems that provide continual, naturalistic assessment of the cognitive and affective status of older adults.

Whereas currently most cognitive assessment is done in a clinical setting, we use sensor-based monitoring combined with adaptive algorithms to assess people’s level of functioning in a continuous way. The adaptive lighting function in ALADIN was pre-conditioned on successfully meeting the following tasks:

- clarifying robust psychophysiological target values
- determining the range of lighting stimuli
- selecting appropriate search algorithms
- defining the parameters of adaptive algorithms

Besides, we had to find solutions for the following challenges:

- miniaturization of physiological sensor technology
- designing reasonable lighting solution
- integration into common building management systems
- usability and accessibility of hardware and software

The empirical data gathered in the private households of twelve older adults can help refine the prototype both in terms of hardware and software. We have decided to make the results and findings publicly available and thus contribute to the growing pool of knowledge on how to make technology more ageing-friendly.

End results and exploitation plans

The ALADIN prototype comprises the following components:^

An intelligent open-loop control and biofeedback system which can adapt various light parameters such as intensity, light directions or colour in response to the psycho-physiological data, which are continuously registered by the system.

A control system that can be manually adjusted via graphical interfaces and allows the resetting of all light parameters to their default values. To achieve truly ageing friendly interfaces design-for-all principles are applied which take into account changing levels of capability due to age.

An application that can assist older people in better understanding their own affective-cognitive states including their circadian rhythms and enable them to take responsibility for regulating them.

Both hardware and software applications have been developed to allow easy integration with other ICT building blocks, thus becoming part of a general assistive environment. Therefore the ALADIN system, or parts of it, can also be integrated into third party applications at various levels. Besides, due to its open architecture, the system can easily be extended to include other environmental factors such as temperature, acoustics, colour or information displays. The modular extensibility has been further enhanced by adapting the system architecture to use an XML-based communication protocol between server and clients.

Overall the strategy to use „normal" products in an innovative way proved to be very adequate in terms of functionality. Future efforts to improve the system or even to make it ready for serial production can concentrate on the core functions like optimising the software, designing a less intrusive and more reliable sensor, and producing more cost-efficient lighting devices. Besides, it should be possible to make ALADIN compatible with any existing TV.

The findings from the field tests show that frequency and duration of using automatic light adaption have some statistically significant positive correlation with indicators for wellbeing. The genetic lighting algorithm of ALADIN prototype had a positive influence on the cognitive performance of elderly people, whereas the annealing lighting algorithm of ALADIN prototype had a positive influence on the relaxation ability of elderly people, Perhaps due to the way the system was introduced and communicated, ALADIN was not perceived as one integrated system, but in the eyes of the test persons there were two: an interactive gaming computer - the brain-jogging exercises were particularly appreciated - and a powerful lighting device. The „missing link” between the two, namely the automatic light adaptation, happens subliminally and therefore cannot normally be perceived by users. Whilst healthy users want to be in control and wish to know what and why something is happening, the automatic subliminal functioning might be advantageous for older people who suffer from dementia, for instance.

For the time being, the price of the system is still a major barrier to marketing the system on a large scale. Even if we succeed in bringing the price down due to economies of scale, the price would still be beyond the means of most older people unless the costs are covered by their health insurance. Alternatively, the system can be targeted at nursing homes or care facilities for the elderly. This, however, requires a certain measure of adaptation since at the moment ALADIN is designed for single rooms in private households.

When the prototype was approaching completion we started our discussions with representatives from major players of the lighting industry about possible ways to exploit the system and/or the results of our research. They are particularly interested in the use of intelligent lighting for increasing the productivity of office workers. Although people have lots of hunches about the sort of lighting that can enhance productivity, so far it has not been possible to quantify either the light parameters or the effects. **Shift workers**, in particular, stand to gain from the work performed in ALADIN.

Another promising avenue to pursue both on the basis of our empirical results and other relevant studies is packaging intelligent lighting with social and technical support measures. The field tests have shown that **user acceptance** greatly depends on the amount of social interaction. Similarly, intelligent lighting can be offered as part of a portfolio of services for ageing-friendly housing and living. Actually, the business cases of both newly founded companies are based on this approach, i.e. combining assistive technology with other services for older people.

An important lesson we learned in the field trials was that the benefits of an assistive technology had to be very clear, otherwise it would not be taken up. This is why the use of **lighting for navigational and security purposes** should be looked at more closely because in the survey conducted to capture user requirements a majority of the elderly expressed their fear of falling. Appropriate lighting could greatly contribute to reduce the risk and thus fear of falling. Besides, staff from nursing care facilities and old folks´ homes have repeatedly expressed their need for orientation aids especially for people suffering from dementia. As these aspects were out of scope as far as ALADIN was concerned, partners have incorporated them in plans for new research projects.

However, whilst there is still a great deal of further research and development to be done, the business scenarios developed by the individual partners show that they hope to exploit the findings from the project in commercial terms as well. Probably the best testimony to partners' commitment to and belief in the future relevance of ALADIN-related results is the fact that two spin-offs have come out of the project which involve both academic and industry partners from the Consortium.

Contractors involved

The Consortium consisted of four academic partners and three small and medium sized enterprises (SMEs) who received approximately 40% of the total project funding. It comprised the following partners and contact persons (including their contact details):

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All partners of the consortium were involved in most phases of the Project to varying degrees. The University of Applied Sciences Vorarlberg (FHV), the coordinating institution, was involved in all work packages pulling together the different strands of the project to turn it into a coherent whole. For the user requirements analysis, the lead was with the Generation Research Program of the Ludwig-Maximilians-Universität in Munich (LMU-Muenchen) and APOLLIS, the Institute for Social Research and Opinion Polling in Bolzano, Italy. They also played a major role when it came to analysing and evaluating the results from the field tests.

For software and hardware development, FHV cooperated closely with Becker Meditec (BMT), a small company specialising on sensor technology, the Budapest University of Technology and Economics (BME), the Bucharest Polytechnical University (UPB) and Bartenbach Light Laboratory (BLL), which is well-known for light planning with clients all over the world. The lab tests were conducted by BME and BLL.

Close cooperation was also important for organising and conducting the field trials which required a concerted effort on all sides. They took place in twelve different households in four locations, followed a complex test design and were accompanied by support staff who had to be trained beforehand.

All partners spent considerable time and effort on dissemination and exploitation activities. The Consortium organised three international conferences to raise awareness about the project and its results. The academic partners published a host of articles in scientific journals and all the partners engaged in PR activities at the levels and with the channels most appropriate to their different target groups.

1 Project Execution

We start out by giving a brief overview on the impact of light on people's wellbeing and health, especially of the elderly, and clarify the concept of ”wellbeing”. We discuss the results of the empirical survey conducted in the South Tyrol and the theoretical framework that underlies the emphasis on qualitative methods and ensuring societal acceptance. The theoretical underpinnings also include the general model which was developed to capture the correlations between environmental variables and the psycho-physiological states of older adults.

We then present the results of the lab tests which were conducted to define the psycho-physiological target values for both relaxation and activation and to identify the light parameters relevant for these purposes.

The next section is devoted to a description of the ALADIN prototype. This comprises the hardware prerequisites and the technical architecture as well as the software architecture, the different applications and the algorithms developed for adaptive control.

In Section 3 the results obtained in the course of the field trials carried out in private households are discussed. Given the vast amount of empirical data the analysis took longer than expected and led to an extension of the project. Finally, we explore the possibilities for exploiting the findings of ALADIN and discuss the various application scenarios.

1.1 Background and methodology

1.1.1 The impact of lighting on people's health and wellbeing

Light affects the elderly mainly in terms of sleep quality, changes of mood and cognitive performance as well as the metabolic system. The negative impact of poorly designed or maintained indoor lighting resulting in unbalanced luminances in the field of view, glare, wrong intensities and light colors (spectra), flicker etc. has been documented (Heschong, 2002; Schweitzer et al, 2004; Ulrich, 2001). These intensify existing vision problems, add to eye fatigue and headaches and contribute to a loss of concentration.

Chronic sleep disorders are among the most widespread complaints in old age. A sound sleep-wake cycle enables people to lead an active social life and participate in social and leisure activities. Besides, with advanced age, many people suffer from reduced mobility and thus are limited in their outdoor activities or may even become home-bound. Lack of daylight can be counter-acted by increased illumination to prevent seasonal depression or sleep disturbances. The results of studies of nursing-home patients and hospitalized elderly patients suggest that increased daytime light exposure, measured by duration and intensity, has an impact on night-time sleep quality and consolidation (Shochat et al, 2000) We also have empirical laboratory evidence for the superiority of so-called ”dynamic lighting”, which provides light outputs varying over time, for visually demanding activity (Abdou, 1997). As natural lighting is almost always dynamic, there are probably evolutionary mechanisms in humans that make them prefer a certain dynamism of lighting.

Impaired vision is one of the most common problems we face with advancing age usually caused by physiological and pathological changes in the eye like cataracts or long-sightedness. The diameter of the pupil that controls the amount of light entering the eye has been found to get smaller with age. The extent of this relative reduction in diameter is even more prominent at low light levels. This is compounded by the older lens becoming less transparent. The effect of ’normal’ ageing can be further exacerbated by various other damages to the retina due to diabetes, the incidence of which also increases with advancing age. To compensate for diminished vision, the level of illumination has to be increased up to three times for older people, which makes higher standards in lighting in older people's homes necessary, e.g. through increasing light levels, improving colour perception and increasing contrast.

Despite the abundance of studies on the effect of lighting there still remain many questions . Among the lacunae in our knowledge is the amount of light required, the most effective way of administering light, whether there is any adaptation effect as there is in the visual system, the effect of different spectra and the influence of the timing of light exposure (Boyce and Mcibse, 2006).

1.1.2 Wellbeing -a multifaceted concept

Both the empirical and desk research about health and wellbeing in advanced age have shown that wellbeing is influenced by a great variety of factors (Mayring, 1987). Leading an autonomous life in one's own home and being capable of performing one's daily activities more or less independently have emerged as crucial factors. Besides, the successful handling of strains and crises and a system of medical care and social support that are adapted to the individual's needs have to be considered essential prerequisites for achieving and/or preserving a sense of wellbeing with older adults. The advice and support application, which is an important component of the ALADIN system, is aimed at:

- The preservation of an active, independent lifestyle
- The preservation of physical and mental fitness
- The avoidance of physical and psychological diseases
- The maintenance of an adequate supportive system

Our approach to health and wellbeing comprises five dimensions, namely mobility and physical fitness, communication, infrastructure (esp. home environment), competences and skills as well as mental health. Most recommendations given in the advice application address several of the above-mentioned dimensions of health, which should be regarded as a complex system, the components of which are interdependent.

Early on in the project it was decided to include biofeedback as a component of the ALADIN system although this was not foreseen in the original project plan. Biofeedback can be considered as a useful therapeutic method for treating a multitude of diseases. Within the scope of ALADIN, biofeedback is regarded as a promising method for mental and physical relaxation. It makes subtle bodily functions perceptible to the user who receives feedback through acoustic or visual channels. The learning process is reinforced by immediate feedback.

1.1.3 The bio-psycho-social model as a framework

Although the general model for modelling the correlations between environmental variables and the psycho-physiological states of older adults was formulated right at the end of the project, its development stretches across the whole duration of project. However, it was only when all the different pieces of the puzzle came together and fell into place that it was possible to translate all the various ideas, expectations and assumptions into a concrete framework.

First of all, our approach is based on the concept of **salutogenesis** which was developed by the American/Israeli sociologist Aaron Antonovsky (1979). According to this model, health cannot be understood as a state but has to be conceived as an ongoing process. Along with this idea goes the concept of a continuum between health and disease. A person's state of health dynamically moves within this continuum. The process of moving on this continuum embraces several variables which have a substantial influence on the development of health, i.e. biological premises, psychological state and social embedding. The ALADIN project is situated within the three respective variables. Besides, the ALADIN prototype includes a fourth variable to influence the development/maintenance of health of elderly people, i.e. technological support.

Secondly, the concept of **open and closed-loop** systems came to play a major role in the development of our general model. Whilst an open loop system refers to a controller that does not use feedback to determine if its input has achieved the desired goal, a closed-loop system uses feedback on how the system is actually performing. This allows the controller to dynamically compensate for disturbances to the system. Finally, we ended up by defining a model which encompasses the interactions and interdependencies of the variables involved in salutogenesis and which illustrates the effectiveness of open and closed-loop systems.

AAL technologies can be conceived as socially-embedded technological subsystems that are able to dynamically interact with biological organisms and therefore have an impact on the biological, psychological and social levels. For our purposes, we extended the **bio-psycho-social model (BPS)** to include technology. The technological device, i.e. the ALADIN prototype, may have an impact upon the biological, psychological and social dimension of an individual. Utilizing an extended BSP model that also incorporates the environmental level that may be influenced or altered by technology, can take account of the prolongation of the time during which elderly people can live independently in their preferred environment – one of the primary aims of AAL solutions.

1.2 Analyzing user requirements

Before describing the empirical study that was conducted to capture user requirements as well as the lab tests and the tests carried out to define the psycho-physiological target values we will briefly outline the methodological underpinnings of our approach.

1.2.1 User-centred design approach

Getting to know one's target group is essential for the future acceptance and use of any assistive system. To find out what users really need and want, it is not sufficient to rely on published data on demographic change and concomitant trends, although these may provide a useful starting point. Instead, empirical research using mostly qualitative and ethnographic methods such as interviews and observation is called for. Also, the lessons learned from previous AmI projects were taken into account such as MavHome (Cook et al, 2003), the Cyber Assist Project for Ambient Intelligence (Nakashima, 2007) or the Philips Home Lab (De Ruyter, 2003). Our approach is very much in line with Philips' vision of ambient intelligence[1], namely: People living easily in digital environments in which the electronics are sensitive to people's

needs, personalized to their requirements, anticipatory of their behaviour and responsive to

their presence.

A further cornerstone of our approach are the scenarios outlined by the ISTAG Group according to which AmI is a pervasive and unobtrusive intelligence in the surrounding environment supporting the activities and interactions of the users (ISTAG, 2002). The Report has identified different characteristics that contribute to the societal acceptance of AmI , namely:

- Facilitate human contact
- Be orientated towards community and cultural enhancement
- Help to build knowledge and skills for work, better quality of work, citizenship
- and consumer choice
- Inspire trust and confidence
- Be consistent with long term sustainability both at personal, societal and environmental levels
- Be controllable by ordinary people

These ideas were at the core of our endeavours. Throughout our project we have also had in mind the barriers that may hinder the acceptance of the AmI approach. When trying to outline an AmI roadmap, the following end-user attitudes have been found to slow down the take-up of assistive systems (Friedewald and Da Costa, 2003):

- People do not accept everything that is technologically possible and available.
- People need resources/capabilities to buy and use technologies (money, time, skills, attitudes, language, etc. that are not evenly distributed in society.
- People make use of new technologies in ways that are very different from the uses intended by suppliers.

The empirical study conducted at the outset of our project to define user requirements as well as the feedback obtained in the course of the field trials very much confirm the importance of both the focus on activity support and the contributory factors for user acceptance outlined above.

[1] 1 See http://www.research.philips.com/technologies/projects/ambintel.html

1.2.2 Empirical study to capture user requirements

In the first few months of our project, APOLLIS, an Italian social research organization, carried out 196 face-to-face interviews in the Autonomous Province of Bolzano. The reason for choosing this region was its cultural mix of German, Italian and Ladino speakers. The main goal was to describe typical every-day activities of people aged 65+ to model one-room/one-person use scenarios for the ALADIN prototype. Not surprisingly, watching TV emerged as the most wide-spread activity in virtually all the surveyed households. Mentally or visually more demanding tasks such as reading, handicrafts, or solving crossword puzzles, are much more diffuse and difficult to standardize. Besides, the same activity, e.g. cooking a meal, may be stressful for one person, whilst another person may find it relaxing. The consortium therefore decided to concentrate on activation/relaxation effects rather than support specific tasks.

At the same time, APOLLIS surveyed user requirements concerning the different components of the ALADIN system like lighting devices, user interface, and body sensors and investigated people's attitudes to new technologies in general. The interview data were supplemented by the interviewer's personal observations and photo documentation of people's housing conditions.

The analysis of the detailed data shows that the population aged 65 and over is very heterogeneous: most people are still active, they may be working (e.g. farmers) or be engaged in volunteer work, they travel, they care for younger or older family members. Contrary to wide-spread belief, big multi-generational families turned out to be not a relict of the past: although mostly located in different households due to higher mobility, it is encouraging to learn that up to the age of 75 years elderly people tend to be givers rather than receivers of social support in the family and neighbourhood network. We have to look at those of very advanced age (e.g. 75+) to find a notable prevalence of age-related disorders, mostly chronic conditions such as rheumatic pains, diabetes or dementia. The "older elderly" with limited mobility, restricted access to daylight and a reduced social environment represent an important target group for ALADIN and other assistive systems. However, given the focus on autonomous living and private households of the project and the overall AAL programme, the majority of people recruited for testing the prototype and its various components belonged to the active and healthy segment of the older population.

The ability of elderly people to imagine the benefits of new technologies for independent ageing proved rather limited. This, of course, may well change with people's increasing familiarity with them during their working lives. Typical reactions are that technology is useless or too complicated, that it makes dependent or threatens to reduce social contact. User expectations towards technology are therefore difficult to ascertain. Overall, the following conclusions can be drawn with a view to increasing future acceptance:

- Light devices must correspond to the sensitivity and limited adaptability of the elderly's eyes. Glare effects and fast light changes should be avoided.

- The whole installation must either be a 'camouflaged' supplement to the existing infrastructure or correspond to individual aesthetic preferences.
- Since motivation to use sensors is mainly correlated to safety matters e.g. automatic emergency call devices, safety concerns have to be taken into account.
- As long as we have to deal with a high share of computer non-users within the target group, maximum attention is to be paid to the design of the user interface.

1.2.3 Tests in a laboratory setting

A series of laboratory tests were conducted to determine the psycho-physiological target values for both relaxation and mental activation and examine the impact of various light parameters on older adults. Preliminary to the lab tests, we defined the criteria for our test population. The elderly person should live on his or her own, spend most of his or her time in the apartment or house and regularly watch TV, read newspapers, or perform some pastime activities in a particular room. The daylight situation in this room should possibly be such that the person normally needs artificial light for a specific period of time to perform daily routines. On the one hand, the test persons should be mentally fit enough to make active use of the ALADIN system, on the other hand they should suffer from certain constraints such as limited mobility that prevent them from engaging in frequent outdoor activity in full sunlight. The excluding factors include serious cardiovascular illnesses, serious neurological or psychiatric illnesses such as depression, epilepsy, severe dementia or serious diabetes. In connection with visual disturbances a serious state of cataract or glaucoma were ruled out. Besides, the excessive consumption of alcohol or caffeine was considered a reason for exclusion, since this might distort the results. As was to be expected, recruiting suitable test persons was quite challenging.

Investigating the impact of different light parameters. The Bartenbach Light Laboratory, a well-known lighting design company located near Innsbruck, Austria, carried out tests for defining the psycho-physiological effects of various light parameters such as light intensity and color temperature and tried to establish correlations between light parameters as independent variables and physiological biosignals (blood pressure, heart rate, respiration rate, skin conductance and muscle tension), cognitive performance and subjective perception rated by questionnaires. The tests at Bartenbach Light Laboratory pursued two objectives:

1. Investigate the effects of different lighting situations on older adults in terms of psycho-physiological impact, subjective perceptions and performance.
2. Produce recommendations for the prototype lighting system to be installed for the field tests.

Fifteen test persons, 9 female and 6 male, participated in two test runs each. The average age was 69 (min: 65, max. 82). The data was collected within a time-span of approximately 2.5 hours by pair-wise random selection of bright and dim light situations. The psychological activation of the elderly people was quantified as the difference of correct answers and reaction times in the continuous performance test. First of all, the test was taken in standard lighting and repeated after five minutes' exposure to test lighting. The psychological relaxation of elderly people was measured by collecting blood pressure data every minute and calculating a relaxation parameter out of the time-series of systolic blood pressure values. Overall, the different lighting situations showed a clear impact on older adults both in terms of activation and relaxation. The effects of lighting could be shown in:

- the test persons' subjective assessments as reflected in the questionnaires,
- the performance tests which measured the test persons' ability to concentrate, and
- the heart rate variability analyses

Bright light produced the most significant effects in the performance tests. The relaxing effects of all the dim light situations could be shown in the heart rate variability (HRV) analyses, especially in the very low, high and middle heart rate frequencies.

Based on these results we can conclude that bright light of at least 500 cd/m^2 and 6500 Kelvin is needed to achieve activation in older test persons. In practical terms this means that the lighting system should aim at providing a colour temperature between 3000 and 8000 Kelvin and a brightness level of max. 750 cd/m^2. The adaptive lighting system therefore has to be dimmable in the range from 0 to 750 cd/m^2 .

1.2.4 Defining psycho-physiological target values

Our Hungarian partner, the Budapest University of Technology and Economics, was responsible for defining the optimal psycho-physiological target values for the successful accomplishment of mentally or visually demanding (VDT) every-day activities. Target values in electrophysiological measurements are the values which represent the desired state of alertness or relaxation. They need not be fixed numeric values, but can be desired trends (increasing or decreasing) or local extremes (maxima or minima). The psycho-physiological target value indicates the psychological state associated with success or failure in a well-defined situation. The intention was to operationalize the mental and physical fitness in terms of alertness or relaxation by measurable indicators such as blood pressure, heart rate, respiration rate, skin conductance or ECG.

The final sample consisted of 30 test persons, 24 women and 6 men. The low number of males was due to the bad health status of men as well as their low representation in this age group. This was a problem that we encountered in other countries as well when recruiting test persons although not to quite the same extent. The age range was between 65 and 84, with an average of 71 years. The total time of data collection per person was approximately 4 hours between 8.00 and 12.00 am. Heart rate, skin conductance, muscle tone as well as respiratory amplitude were measured. The laboratory experiments were conducted under the same lighting conditions as those in the Bartenbach Light Laboratory.

Skin conductance response (SCR) turned out to be the most appropriate psychophysiological target value for the envisaged automatic lighting adaptation, i.e. the intelligent control loop. This parameter proved to be the most sensitive for different activities since a very clear and practically important relationship with activation and relaxation levels was found. Besides, this relationship does not only have statistical significance but shows very high absolute differences in pair-wise comparisons. As a further useful benefit, skin conductance response shows no habituation effect. Heart rate emerged as the second best psycho-physiological target value. Heart rate significantly corresponded with the high activating and relaxing situations. The absolute differences, however, were very small. All the other psycho-physiological parameters did not prove to be sensitive and/or specific enough due to very high individual differences.

1.3 User testing

1.3.1 Usability testing in the development phase

In line with our participatory and iterative development approach we carried out both heuristic inspections by experts and end-user tests in the development phase. Given our specific target group, i.e. older people with various impairments such as diminished vision, the user interface of ALADIN 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 a TV set could be found in virtually all households, it was decided to implement the adaptive lighting system on a computer with added TV functionality.

Interactive TV poses special challenges: watching TV is normally characterized by a “lean back” attitude whereas working on a computer is normally associated with a “lean forward” attitude. The human computer interface has been conceived with an active user in mind whereas TV systems are traditionally aimed at passive consumers. A TV screen is normally placed at a distance of a couple of meters from the viewer and has a lower resolution than a computer. When designing the screen layout we cannot use the full screen because TV sets vary in terms of the size used for presentation.

The so-called “safe area” can be reckoned to be about 10% smaller than the full screen, or about. 576 x 460 pixels.

The first usability test was conducted early on in the project with a HTML dummy with 12 senior citizens between 65 and 84 years old to examine the screen design of the prototype controlled by a remote control. We assumed that our target users would be familiar with handling *remote controls*. Bernhaupt et al. [4], however, have observed that although people may still want the remote control as an input device, it is perceived as too complex and difficult to use by many. They would prefer a universal remote control with only one button which is integrated with a display to inform users about what they have to do next.

The 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.

Mock-up lab testing. The first ALADIN prototype with TV and remote control was carried out with ten clients in a nursing home (65 - 94 years). Users liked the overall graphic design (font, colours, contrast) and found the GUI easy to navigate, provided that the number of navigation elements was kept to a miminum.

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

- The majority of users prefer number keys to cursor keys.
- 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. biofeedback, sensor belt) have to be replaced with simple ever-day terms.
- Users prefer an information structure with a very flat hierarchy

As far as sensor technology was concerned, the end-user tests led us to discard the chest belt originally envisaged for capturing biosignals. Test subjects found it too difficult to attach to their bodies because this required a degree of motoric dexterity and flexibility that even quite a few of the young assistants did not possess. As a result, the sensor expert in the consortium developed a biosensor glove in the run-up to the field trials. The change in sensor technology brought about a change of methodology: instead of measuring skin conductance response (SCR), peripheral pulse was measured by means of photoplethysmography (PPG) in the field trials.

Feedback from the users led to a series of improvements in the software, e.g.

- error messages when users forget to switch on the data glove,
- an hour glass to indicate that a some function is in progress,
- redesign of the way biofeedback is given due to occasional misinterpretation.

1.3.2 Special challenges related to field trials

As in user testing in general, planning and organizing the field trials comprise preparing a test design, defining selection criteria for test persons and recruiting suitable test persons. When implementing a prototype in private households, however, particular ethical and legal issues arise. In our case, the test design had to take into account the constraints imposed by the high costs of the prototype and the limited time resources available on the part of the partners responsible for the field tests. We also had to take out insurance to cover any damages that might be incurred as a result of the installation of the lighting prototype.

Ethical Issues. An important concern is achieving a balance in the relationship between the demand for a better quality of life and the studies that aim to achieve this on the one hand, and the rights of the research participants on the other. In ALADIN, obtaining informed consent and the protection of personal data proved to be the most important issues and played a role at all stages of the research process, i.e. from the requirements analysis by means of interviews to user testing and dealing with research outcomes. Policies regarding informed consent in usability testing are developed by organizations on the basis of generally agreed principles concerning the treatment of human participants. Those principles plus additional ones are enumerated below. Seven of these principles are derived from the related discussion in Dumas and Redish [5]. There is one more principle added in regard to waivers.

1. Minimal risk. Usability testing should not expose participants to more than minimal risk. Though it is unlikely that a usability test will expose participants to physical harm, psychological or sociological risks do arise. If it is not possible to abide by the principle of minimal risk, then the usability professional should endeavour to eliminate the risk or consider not doing the test.

Dumas and Redish [5] citing the Federal Register state that minimal risk means that the probability and magnitude of harm or discomfort anticipated in the test are not greater, in and of themselves, than those ordinarily encountered in daily life or during the performance of routine physical or psychological examinations or tests.

2. Information. Informed consent implies information is supplied to participants. Based on the suggestions of Dumas and Redish, we supplied the following information: the procedures we would follow; the purpose of the test; any risks to the participant; the opportunity to ask questions; and, the opportunity to withdraw at any time.

3. Comprehension. The professional needs to ensure that each participant understands what is involved in the test. This must be done in a manner that is clear and unambiguous. It must also be done so as to completely cover the information on the form. The procedure is about the participant making an informed choice to proceed with the test and therefore they need to be allowed opportunity for questions. Clearly one possible outcome of applying this principle is that the person involved may choose not to participate.

4. Voluntariness. Professional behavior influences participant involvement. Participants should not be rushed, nor should facilitators fidget while the participant reads the form. Coercion and undue influence should be absent when the person is asked to give their consent to participate in the test. Excessive pressure might come in a number of subtle ways that one needs to be cautious of.

5. Participants' rights. Countries vary as to their recognition of human rights. Even where there is general agreement, definitions of those rights and interpretations of how they apply vary. Participants should have is the right to be informed as to what their rights are. Karat [6] reviewed the codes of ethics of 30 national computer societies and found that they shared several major topic areas. The first on the list addressed the need to respect the rights of people involved with the technology. According to Dumas and Redish [5] the rights most relevant to usability testing include the right to leave the test without penalty, the right to have a break at any time, the right to privacy (such as not having their names used in reporting the results of the test), the right to be informed as to the purpose of the test and the right to know before the test what they will be doing.

7. Confidentiality. Confidentiality is different from the participant's right to privacy; it refers to how data about the participants will be stored. The ACS (2000) code stipulates that it is obligatory for members to preserve the confidentiality of others information. The ACM (2000) code has specific clauses on constraining access to certain types of data, and on organizational leadership to ensure confidentiality obligations are adhered to within organizations. In remote testing this can be extended to electronic data-logging over the internet.

8. Waivers. Permission needs to be obtained from participants to use materials such as questionnaires, audio and video recordings (and their transcripts). In many countries they have the right to refuse to give waivers. Participants should be given the option of having the data used for the purposes of the test, or of also having it used in a wider context. If the latter, then the consent form should state in what further ways the data will be used, so that an informed decision can be taken by the participant. Such permission should state the purposes for which the material will be used.

Informed consent is both a process and a formal record of the process. That formal record is typically a form, but may also be another type of recording, such as video. In our case we used a form that was signed by each participant.

Interviewing old people. We had to acknowledge that we were interviewing old people for this research and that taking part in an interview was a demanding experience for both interviewer and participant. Past research has suggested that such interviewing is both possible and highly rewarding. However, we must take into account that failing eyesight, hearing, mobility, cognitive impairment etc may affect interviews. Interviewers have to be prepared to take their time, repeat themselves, ask for clarifications, listen to repetitions, help them to orientate to the questions with reference points for reminders (e.g. anchoring events to dates). Interviewers should keep the interview very focused and watch out for participant fatigue. In our project, they were told, that it would be better to return at a later date than to conduct a lengthy and tiring interview.

What also needs to be taken into account are issues of power relationships. Older people might see researchers as high status compared to themselves and may easily defer to a researcher's opinions and ideas. Inequalities in power throughout the interview could stem from gender (male interviewer-female participant), age (younger interviewer-older participant), employment status, (employed interviewer-retired older person) and so on. We needed to think carefully about how such issues might have affected each interview and discussed this in our reflexive analysis. In situations where power inequalities were evident it was helpful to keep reassuring the participant that they were the experts and we were there to learn from their experiences. This helped to put them more in control of the interview, just as accepting a cup of tea allowed them to relocate the interview as a social situation which they were familiar with.

1.3.3 Possible distortion effects in field trials

In the analysis of the objective effects of the whole system the dependent variables, that is the outcome in terms of well-being and mental fitness are clearly defined by the survey instruments used and the data collected. Yet the definition of the independent input variables is much more complicated as we are not dealing with a laboratory test under controlled conditions but with a real life field test in which almost everything can happen and distort the assumed correlation between the application of the ALADIN components and the output. Besides a general Hawthorne effect, the fact that the situation of observing and surveying the test persons already has an effect on them, has to be taken into account (Adair 1984).

We can identify five sources of possible distortion and interference with the objective ALADIN effects:

Time effects: Three months of testing with alternating algorithms are sensitive to time effect because we cannot exclude that the outcome measured in one period could be a consequence of a factor present in a former period. Only the sequence of adaptive lighting algorithms (genetic and annealing algorithm) could be rotated to control sequence effects. This does not affect the evaluation of the system as a whole but it influences the weighting of the different components and periods.

Learning effects: Habituation and learning are in some way correlated to time effects and mainly affect measurements of mental fitness. Concerning the performance in the activation exercises it is well known that regular training leads to improvements. So we should expect a notable increase in performance even without further supporting factors.

Social support effects: Coaching and technical assistance are a vital part of a field test because we cannot expect the test persons to use the system without any help right from the start. We also know from the requirements analysis that any technology which replaces social contact would be rejected. Social support therefore has to be recognized as one of the main „disturbing" factors. Some control is possible through the personal diaries and the annotations of the assistants.

Particular events: Only in an isolated laboratory and under constant control can we exclude incidental distortions as they often happen in real life. In the analysis of the data we also have to consider meteorological phenomena as well as illness or social problems which we can only partly reconstruct from the collected data.

Way of use: A more interfering than distorting effect is closely correlated to the real life scenario. The test persons were free to use ALADIN as they wanted as long as they fulfilled some minimum criteria. This means that date, frequency and duration of usage of the different ALADIN components vary from test person to test person. To compensate for this, either complex modeling of the independent variables or a restriction to single case analysis are required. We chose the latter option.

1.3.4 Lessons learned regarding usability testing of AAL applications

As is usually the case with such complex endeavors that consume lots of time and human resources, one would like to have another go to get everything right straight from the start. This is why it is so important to derive lessons learned from one´s experience. Even if you assume that you have prepared the field trials very well, cleared all the ethical issues, organized the logistics and written up detailed instructions, this does not ensure that they will run smoothly. In our case, matters were complicated by having three locations for conducting the field tests. On the whole, people prefer calling on a human person/expert rather than consult the manual or FAQs on the Web. Therefore, a need for central coordination throughout the field trials has emerged as essential for efficient implementation.

Another important lesson learned is that for measuring factors such as wellbeing, sleep quality and attitude to life the field trials should last for a whole year. This would also help neutralize the novelty effect in the beginning. In the focus group discussions, it also became clear that the test persons who used ALADIN in the winter months were overall more positive than the ones who used it in spring. Whilst we were aware of this, the high costs of the lighting system made this impossible. Having three systems run in parallel was the most we could afford.

The need for very precise instructions does not only apply to the test persons but also to the assistants and the people involved in installing the system. Although before the field tests detailed manuals for the organizations and the coaches involved in the field trials had been prepared, discussed and distributed to all the relevant parties, this still proved insufficient. Especially, we underestimated the need for technical assistance for installing the system. It might therefore be advisable to appoint a technical expert to handle the installation in all locations and who can be contacted when a problem arises.

2 The ALADIN prototype

Both the results of the lab tests and the test runs with end-users fed into the development of the ALADIN prototype. It constitutes an intelligent open-loop control and biofeedback system which can adapt various light parameters such as intensity and colour in response to the psycho-physiological data. These are continuously registered by the system. It can be manually adjusted via the graphical interface and allows the resetting of all light parameters to their default values. As you can see in the Figure below, it comprises the following components:

Fig. 1. ALADIN system as deployed in the field tests.

As can be seen in Figure 1, the system comprises the following applications:

- Television (Fernsehen)
- Automatic lighting (Automatisches Licht)
- Manual lighting (Manuelles Licht)

- Exercises (Übungen)
- History (Rückschau)
- Advice & support (Wohlfühltipps)

The user can select between these options by pressing the number buttons 1 to 6 or move the cursor to the desired option and press OK on the remote control. Each of these applications works independently and has to be started deliberately by the user. ”Automatic lighting” adapts the lighting to achieve an activating or relaxing effect. Because of the great diversity of situations, events or individuals, the direction of change or adaptation is unlikely to be known beforehand. We have opted for genetic and simulated annealing algorithms to implement adaptive control (?). With ”Manual lighting” a user can turn on and off different predefined lighting situations (e.g. reading light) as well as manually modify lighting situations. The application ”Exercises” offers the user a variety of activating and relaxing exercises. Whereas the former comprise various brain jogging exercises, the latter are largely based on the biofeedback method which allows making subtle bodily functions perceptible to the user. ”Advice & support” allows the user to browse through different recommendations aimed at healthy behaviour. Finally, with ”History” the user can view the results of the exercises he or she executed during the last five days. The ”Advice” and ”History” applications derive their input from the results of the exercises.

Both hardware, i.e. the sensor gloves and lighting devices, and software applications have been developed to allow easy integration into building management systems, thus becoming part of a general assistive environment.

2.1 Technical architecture - overview

The general idea of ALADIN technology is to make as few as possible modifications within private households of elderly people. This means that we prefer using already existing and common devices in private households, to replace these devices with new technologies with additional functionality or to introduce only non-intrusive components for some novel features of ALADIN. An important requirement of our project is that it should be possible to integrate the ALADIN lighting system into conventional building control systems. There are basically two ways of ensuring that all components of a building system (lighting, heating, ventilation, air-conditioning, security systems, lifts, access control, etc.) work together smoothly and do not interfere with each other:

1. running all components across a single system, or
2. installing a special system for every individual service to achieve maximum functional efficiency in each area.

We opted for the second possibility and decided to use the LITENET system from Zumtobel Lighting GmbH to control ligthing devices. It provides interfaces to other building services and higher-level building management systems in the form of BACnet and OPC as standardised interfaces. BACnet is a networking protocol, which has been designed specifically to meet the communication needs of building automation and control systems. OPC stands for ”Object Linking and Embedding for Process Control”; the OPC standards aim for open connectivity of industrial automation devices and systems. Thus we can achieve seamless system integration between field buses and computer applications such as the ALADIN software.

The ALADIN software runs on a computer system with interfaces for Ethernet and bluetooth. It contains a Java-based framework for capturing psychophysiological data supplied by a biosignal recorder via bluetooth connection, analyzing these biosignals with regard to the individual cognitive performance defined by the performance-resource function Alvarez et al., and controlling lighting devices (and blinds) according to the results of these analyzing routines. Feedback is given by smart biosensors, which are attached to the human body and operate with a 32-bit microprocessor including an analogue-to-digital converter for eight channels for input and a serial peripheral interface for output.

The biosignal recorder used for the prototype is a wireless adaptation of the Varioport device from Becker Meditec, one of our partners. It measures electrocardiographic, electrodermal, respiratory and body movement indicators and continuously transfers them to the computer system via bluetooth connection. Adaptive algorithms for feature detection, optimization, and learning are active continuously as there is no optimal lighting condition; this depends on a person’s individual psychological state at a particular point of time. For the field trials the light devices were set at 20% of their maximum when using the genetic algorithm. During the phase with the simulated annealing algorithm the lighting condition at the outset was set randomly. The intelligent control loop is started manually by TV remote control and stopped automatically by a specific motion pattern detected by the intelligent unit or by the user.

2.2 Hardware components

As mentioned in Section 2 almost every private household has a television set which is why we have decided to use this as a user interface for explicit input and output. Television devices are used by older people in various ways: with terrestrial antenna, satellite antenna, cable television, together with video recorders, DVB receivers, amplifiers etc. So as not to be restricted to one of these technical combinations we avoid the use of input and output connectors for Euro scart, antenna, component video and audio.

For ALADIN we used a television device with RS-232C port for service and control as well as an RGB port. Graphic outputs are presented best on a screen with a HD-ready television with 16:9 aspect ratio.

Television signals can be received via antenna, Euro scart, or component input. To ensure the accessibility of the ALADIN user interface we recommend a remote control with large keys as well as a tactile and non-slip casing that makes it easier to use for older people. The device should reproduce all the functions of the original TV remote control. The ALADIN prototype was programmed for the Meliconi gum body remote control but all the other universal remote controls could equally be programmed. Therefore in the future, this might be replaced by the one-button device currently being developed by Bernhaupt and colleagues in Salzburg Bernhaupt 2007.

The user navigates the television device as well as the ALADIN software user interface via the remote control. Therefore we need an infrared control system which is able to receive infrared signals from the remote control and send infrared signals to the television device. For ALADIN we selected an infrared control system directly connected with the ALADIN software via USB. The choice of a specific computer device for ALADIN is closely related to the general idea of ambient technology, i.e. implementing computer systems in such a way that the users are hardly aware of them. The Apple Mac Mini computer is small and stylish and can be taken as a common set-top box for television devices. For the benefit of the administrator the computer can be connected with a keyboard and mouse. The user, however, interacts with the ALADIN software only by means of the remote control.

2.2.1 Sensor device

As mentioned before, the biosignal recorder used for the prototype is a wireless adaptation of the Varioport device from Becker Meditec. In the beginning, we worked with a chest belt. Since in the early user tests this proved too unwieldy and difficult to attach by most older people, we had to find an alternative. Becker Meditec, the sensor expert in the Consortium, tested various other sensor devices including so-called ”wearable sensor systems”, but found them inappropriate for older test persons or really any test persons who had a certain amount of ”padding” on their bones since they only seemed to work with very skinny people.

Eventually, it was decided to incorporate the sensor device into a glove. For the final biosensor glove we implemented photoplethysmography (PPG) to measure peripheral pulse on the index finger and implemented electrodermal electrodes to measure skin conductance between index finger and thumb. The user slips the glove on every time he or she wants to use automatic lighting or perform a biofeedback exercise. The smart biosensor glove can be turned on and off by a small power button. The glove has a rechargeable battery inside which has to be reloaded after twelve hours of operation.

A great deal of research is currently conducted to develop unobtrusive and truly non-invasive sensor devices. As mentioned before, the idea of incorporating sensors into wearable T-shirts or other garments sounds very appealing but when put to the test in real-life situations fails to convince. A promising avenue may be the one pursued by Prance and his colleagues at the University of Sussex who have developed sensors that operate by monitoring the displacement current between the body and the sensor input electrode. Thus they are able to dispense with the usual electrolytic paste contact or gel (Harland et al, 2002).

2.2.2 Light installation

For ALADIN we use lighting and control devices from Luxmate, a company that belongs to the Zumtobel Group. The ALADIN system also works with control units of other producers such as Tridonic or Osram . The Zumtobel Luxmate system is addressed via serial interface which in turn communicates with a DALI system. The general lighting control protocol is DALI (digital addressable lighting interface), an open standard in accordance with the International Electrotechnical Commission IEC 60929 standard for fluorescent lamp ballasts. Each piece of operating equipment with a DALI interface can communicate via DALI individually. Using a bi-directional data exchange, the DALI controller (e.g. LM-DALIS) can query and set the status of each light. As a stand-alone system, DALI can be operated with a maximum of 64 devices.

For the ALADIN prototype we need at least twelve devices. The control circuits consist of ten lighting channels with five channels for blue coloured light (e.g. 8000 Kelvin) and five channels for red coloured light (e.g. 2700 Kelvin). A single lighting device is composed of a red and blue coloured light. Furthermore the ALADIN prototype also includes a light sensor measuring the light intensity within the room and at least one manual lighting switch to turn on and off the lighting in the usual way.

In Figure 2 below you can see that the ALADIN lighting system consists of two different components: a direct or indirect suspended down-light, and a ceiling floodlight, both of which can change spectrum, colour temperature, light intensity and directions. For test purposes the lighting solution including the lighting devices, lighting controls, manual switch, and light sensor have been assembled into a compact unit or bus box to enable quick installation in households. In everyday circumstances the ALADIN system can work with every digitally addressable device in a building automation system.

Fig. 2: ALADIN lighting installation

For adaptive lighting, all circuits can use the maximum light variation with all parameters (0-100 %) and in any combination except the two circuits for the direct lighting (table light). A single circuit for direct light has a maximum of 80 % and both circuits together have a maximum of 120 %. To obtain a smooth change, light variation must not exceed 10% per second. Indirect lights are mounted along the whole length of all four sides of the room. The direct light, i.e. the table lamp, produces a great deal of heat, which is why a fan has been added. A bus box contains all the interfaces that are usually included in the building automation system. The light sensor is attached to the table light and normally directed to a window to check the amount of daylight.

2.3 Software Architecture

It is essential that the software architecture of ALADIN be open to allow easy integration with other information and communication systems in buildings, thus becoming part of a general assistive environment. For this reason ALADIN is a platform-independent system which can run on any supported operating system platform. ALADIN has a client-server computing architecture, where the applications are clients who may initiate a communication session. ALADIN consists of several applications and requires at least one server and one client application. The applications include

”Adaptive Lighting”, ”Manual Lighting”, ”Exercises”, ”History View”, ”Advice”, ”Television”, and the ”Main Menu”. Each of these applications has a user interface and an application area. Data between client and server are exchanged via TCP/IP.

An important advantage of such a distributed architecture lies in the fact that client applications are device-independent, which means that the biofeedback application could run on a mobile device whereas the other applications could be installed on a desktop computer. Besides, it allows installing, testing and, if necessary, replacing the various software components independently of each other. The applications have been implemented in Java. However, given the abovedescribed approach it would be possible to implement other individual applications using different programming languages if Java should prove inappropriate for any particular application. Client and server communicate via a specially developed ALADIN protocol at the application level. This means that the client application can instruct the server application to start or terminate recording, to store the results or retrieve records already stored.

The applications ”Adaptive Lighting” and ”Manual Lighting” make use of the Lighting Control package to control lighting devices. The applications ”Exercises”, ”History View”, and ”Advice” either save their data via Data Center package on the server or receive all relevant data via Data Center package from the server. The application ”Exercises” needs the ALADIN Music Player package to play music sequences during the biofeedback exercise.

To start a biosignal recording session the Data Center makes use of the Varioport framework which allows easy access to the data of the smart biosensor glove. The raw data from the biosensor glove are transmitted to the server via bluetooth and saved immediately in a directory. The server informs the corresponding client about the new raw data records. User inputs from the remote control are communicated via the IRControl package to the server part of ALADIN and from the server to the respective client application. All applications with user interfaces need the UI Framework package to provide outputs to the television screen.

Each application can store data (e.g. biosignal results) in the persistence layer. All data are saved as plain text into a directory, the name of which records time and date. Therefore, a client can request raw as well as application data from any particular day. Furthermore, files can be opened using different text editors. What is difficult with this type of implementation is the performance of complex queries combining different search parameters. If this should be required in the future, it can be realized due to the abstraction of storage mechanisms provided by the persistence level which allows easy integration of a database.

ALADIN software consists of two Java-based frameworks to facilitate an efficient and easy development of further applications. One of the frameworks subsumes all sub-routines into a single command communicated between client and server via TCP/IP. Functions such as connecting, disconnecting, sending of requests and receiving the data requested can be performed by extending the client class. The other framework provides reusable graphical elements/components which enables the developer(s) to adapt the graphical user interface (GUI) to different user requirements (e.g. different languages, font sizes, colours etc.). The framework also makes sure that the look-and-feel and navigation of the GUI are consistent across all applications.

2.3.1 ALADIN applications

For automatic light adaptation the user has to select either an activating or a relaxing light situation. According to the user's selection the adaptive algorithm (e.g. simulated annealing or genetic algorithm) starts looking for the best individual lighting condition. Before starting the light adaptation the light sensor checks the amount of daylight within the room. The user receives the information to darken the room if it is too bright for adaptive lighting. The automatic light adaptation is achieved by an open loop circuit modifying the light parameters through the DALI interface and interpreting the biosignals (electrodermal activity and heart rate) measured by the biosensor glove as an individual reaction to these light modifications. The result of this interpretation is used by the adaptive algorithms to find the next best light modification. The intelligent control loop is started manually by TV remote control and stopped manually by the user or automatically when the user leaves the room.

After selecting the manual light option in the main menu, the user is offered different options of light situations on the television screen. The user can select one of these options. There are several predefined lighting situations and one variable light situation where the user can modify the light intensity as he or she wishes. ALADIN consists of an administrator tool to define the light situations which are shown on the television screen and/or are available through manual switches, e.g. romantic dinner light, bright light for visually demanding tasks or whatever.

The exercise application of ALADIN contains a set of different relaxing and activating exercises. After starting this application the user gets the information about the number of exercises on a particular day. Relaxation is achieved through continuous biofeedback from the user's own electrodermal activity or the heart rate. For this purpose the user has to slip over and turn on the biosensor glove. Activation exercises include calculating, text searching, memorizing, and a visual guessing task. The user can select one of these exercises as often as he/she wants to relax or to activate. All the parameters of these exercises can be configured by a configuration file of ALADIN system. After finishing an exercise the user receives immediate feedback on his or her success, i.e. the degree of activation or relaxation achieved. The data are stored in the data centre of ALADIN.

The history view application of ALADIN shows the individual's success in relaxing and activating in the exercises of the past five days. The data base is composed of the results of the exercises which are automatically analyzed every day at noon by the ALADIN system in a two step process. The results are stored in the data centre of ALADIN. The history view application takes this information from the data centre every time when the user selects this option and shows the results of this routine on the television screen.

The advice application takes several recommendations from a set of approximately 250 recommendations depending on the outcome of the results from the exercises executed during the last five days. There are six possible results: too much activation during the morning, too much activation during the afternoon, too much activation during the evening, not enough activation during the morning, not enough activation during the afternoon, and not enough activation during the evening.

2.3.2 Light adaptation algorithms

Dynamically finding specific lighting situations that best support the ALADIN user basically comes down to a trial-and-error procedure. However, with ten individually controlled light circuits, each of which can be set to values between 0 and 255, the number of different possible lighting situations is enormous and therefore it would be impractical to test every single one of them for their effects. Furthermore, one and the same light scene could cause different effects in different situations. One approach consists in implementing uniform search strategies that can find optimal lighting situations by selectively generating new lighting situations and testing them against previously defined target values. ALADIN contains two different algorithms, simulated annealing algorithm (A1) and genetic algorithm (A2). In the field trials the algorithms were tested consecutively for three weeks each.

Simulated annealing is a combination of a so-called hill-climbing search algorithm with a random walk within a state space. Each lighting situation is analogous to a state of a physical system, and the psycho-physiological responses that must be improved are analogous to the internal energy of the system in that state. The hill-climbing algorithm is simply a loop that continually searches a state with a higher value within a state space containing only immediate neighbors. Because hill climbing algorithms can get stuck on a local maximum they are combined with a random walk within the immediate neighbourhood of the state space. This way it is not possible to generate different lighting situations successively. By means of this guided technique a searching path is built based on successive local searching steps from the initial to the best lighting situation.

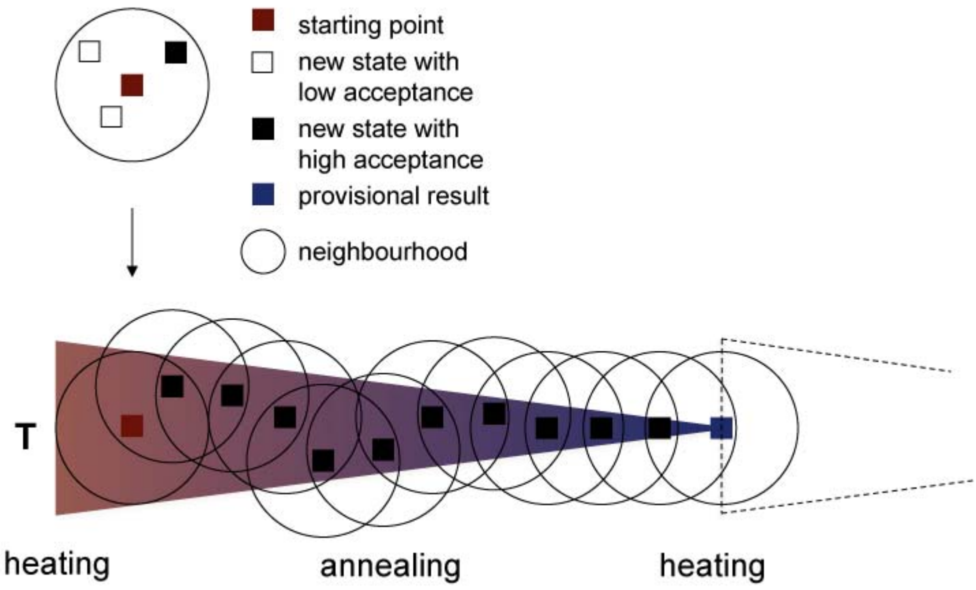

Fig. 4 Simulated annealing algorithm

Each step of the simulated annealing algorithm replaces the current solution by a random ”nearby” solution, chosen with a probability that depends on the difference between the corresponding function values and on a global parameter T (called ”temperature”) that is gradually decreased during the process.

The other approach used are so-called genetic algorithms which resemble evolution in nature and are often used to find good solutions within a huge search space, thus making them popular for optimization tasks. A genetic algorithm is a stochastic search in which successor states are generated by combining two parent states. This algorithm begins with a set of randomly generated states, called the population. Within one generation each state of the population is rated by the evaluation or fitness function. According to this fitness function two states are selected for reproducing new states applying crossover and mutation procedures. In ALADIN a set of different light scenes determined by the individual brightness levels of the lighting devices forms an initial population. These selected light scenes are then tested for psychophysiological effects on the person in the ALADIN controlled room. The more these effects approximate a specific target value, the higher the tested light scenes are rated, and the higher the chance that parts of them will be used in subsequent generations.

These highly rated scenes become the ”parents” and are eventually recombined to form new light scenes. Random mutation can also take place, just like in nature. Once the creation of the new population is finished, the whole process is repeated over and over again. During the course of this process, the generated light scenes should increasingly approximate the desired effect.

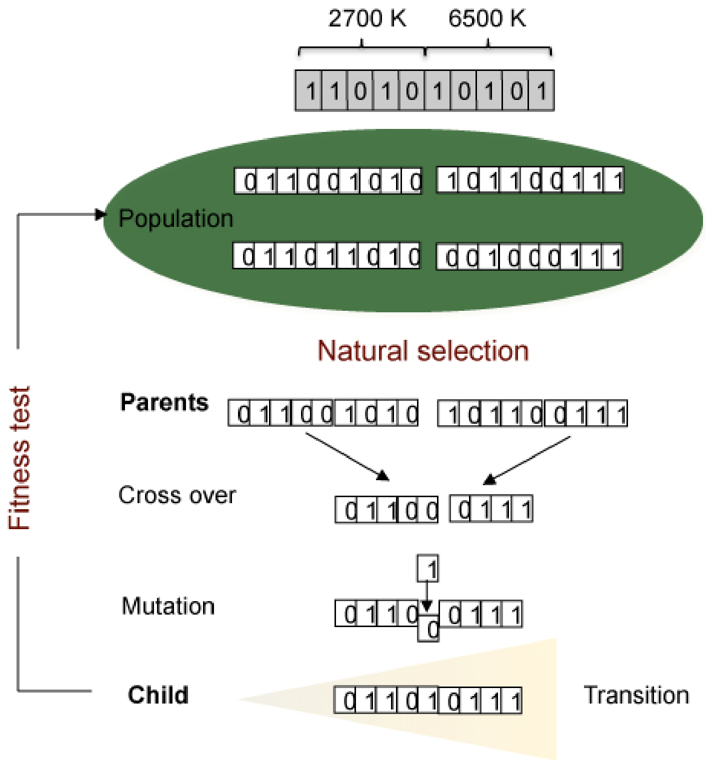

Fig. 5 Genetic algorithm

Both search algorithms are implemented with different time parameters. The simulated annealing algorithm works with a fixed light transition time of five seconds. Then the lighting parameters are held constant and the psychophysiological effects are analyzed until a trend is found within the biosignal. The maximum time window is two minutes. After two minutes a random change parametrization occurs within 20 seconds. The genetic algorithm introduces a new light situation within a dynamic transition time window. The length of the time window depends on the difference between star and end point of lighting situation. Only ten percent per second modifications are allowed. Analyzing psycho-physiological effects is done within a 20 second time window.

Light variation occurs in a very smooth and gradual way from the beginning to the end of transition time. The analysing window should not be less than 20 seconds to equalize artefacts.

2.4 Analyzing biosignals

The parametrization of electrodermal activity (= skin conductance reaction; SCR) is done with the standard deviation curve of the biosignal. Furthermore, for A1 standard deviations are calculated within 1.5 second time windows and then the trend of standard deviations out of all 20 second windows is calculated. A2 measures the time during which skin conductance values exceed the starting value of the assessment period. For heart rate parametrization the inter-beat interval (IBI) from the peripheral pulse volume signal is identified. A1 calculates a trend of mean heart rate out of all 20 second windows. A2 calculates the difference of single mean heart rate of the first and the half of the 20 second window.

For A1, heart rate variation is calculated as a trend of standard deviations of IBI out of all 20 second windows and for A2 as a single standard deviation from IBI for 20 seconds. The results form analyzing the biosignals are then mapped on the same standard scale to be able to add and weight single psychophysiological channels. The psycho-physiological reactions are calculated from the sum of standardized and weighted parameters. No spectrum analysis is performed since this is only possible with ECG and high sampling rate. Adaptation can be stopped manually or by motion sensors integrated into the Varioport or the lighting device on the ceiling. The ALADIN prototype should work without a learning period for the system but should show learning effects over time.

The target values for activation or relaxation are defined by psycho-physiological parameters. The lighting effects as well as the psycho-physiological signals might be different for every individual adaptive lighting (e.g. learning, daytime, conditions and surrounding effects). Therefore a one-time calibration of target values, i.e. baseline definition for target value by measuring and rating, seems to be inadequate. On the other hand, a user-guided calibration with every adaptive lighting session is inefficient and not acceptable to the subjects. In the field trials we calibrated the system with the first biofeedback of each day.

For target value calculation a baseline correction is implemented: for A1 we find the minimum and maximum of the starting psycho-physiological level of SCR, heart rate (HR), and heart rate variability (HRV) within biofeedback every morning. For A2 we find the median of absolute maxima and minima of SCR, HR, HRV in the history of psycho-physiological measurements. Relaxation is defined as 1-20% decrease of SCR, HR, and HRV depending on base line correction. Activation is defined as 1-20% increase of SCR, heart rate and heart rate HR, and HRV depending on baseline correction. A combinatory approach is used to interpret skin conductance and heart rate as indicators for psychophysiological activation and relaxation. In case the test persons are dissatisfied with the adaptive lighting, they can intervene and manually interrupt the adaptive lighting. These interruptions are also good indicators for target values and are logged.

2.5 Analyzing exercise routines

Analyzing the results from exercises follows a two step process: In the first step all results of exercises per period of daytime (morning, afternoon, evening) are combined to single health status values for the ability to relax and the ability to activate in the morning, afternoon, or evening. In a second step, the results of this classification for the last five days are analyzed according to a visible trend in the history for the ability to relax and the ability to activate in the morning, afternoon, or evening. This second step should lead to individual recommendations for the user to increase the health status. The first step of data analysis is performed with artificial neural network (ANN) classification, the second step of data analysis with k-nearest neighbour (KNN) classification.

For non-linear statistical data modelling of the complex relationships between exercise data and health status per daytime (morning, afternoon, evening) ALADIN uses artificial neural network (ANN) classification. A simple feed forward neural network has been implemented where the information moves in only one direction from the input node through the hidden nodes to the output node. There are no cycles or loops in the network.

This multi-layer perceptron with only one hidden layer has 30 input nodes, 35 hidden nodes, and 5 output nodes. The 30 input nodes derive from six different exercises of the ALADIN system with integer values from 1 to 5 as possible results. Each of these possible results corresponds to an input node of the perceptron. The same is with the output nodes where each of these possible results corresponds to a single node. The units of this network apply a sigmoid activation function in the form of a hyperbolic tangent, which allows considering the positive and negative values of the exercise data.

The artificial neural network classification of ALADIN uses back propagation as a learning technique. Here, the output values are compared with the correct interpre tation of experts (physicists and psychologists) to compute the value of predefined error-function. The correct interpretations are described in training vectors. The error is then fed back to the network. Using this information, the algorithm adjusts the weights of each connection in order to reduce the value of the error function by some small amount. After repeating this process for a sufficiently large number of training cycles (10,000 cycles for ALADIN), the network will usually converge to a state where the error of the calculations is small.

For interpreting the time series patterns of combined exercise data, i.e. single health status values for morning, afternoon, and evening within the last five days, ALADIN has implemented the k-nearest neighbour (KNN) classification for activation and relaxation. This search algorithm computes the distance from a query point to every other point in a predefined database, keeping track of the ”best so far”. The query point is a single health status value for the ability to relax or the ability to activate in the morning, afternoon, or evening. The data base consists of the expert data, i.e. some exemplary time series of combined exercise data for activation and relaxation within five days that have been interpreted by experts such as physicists and psychologists. The idea of this classification is to use nearest neighbour search for finding the closest time series pattern in the database to the given time series pattern of the user. Within ALADIN k = 1, this means that the points are simply assigned to the class of their nearest neighbour.

The training phase of the algorithm consists of storing the feature vectors, i.e. selected time series database, and class labels of the training samples (expert's interpretation). In the actual classification phase, the test sample (whose class is not known) is represented as a vector in the feature space. Distances from the new vector to all stored vectors are computed and the closest samples are selected. This algorithm sometimes referred to as the 'naive approach' works for small databases but quickly becomes intractable with increasing size or complexity of the problem. No search data structures have to be maintained, so linear search has no space complexity beyond the storage of the database.

3 Results and Outlook

3.1 Findings from field trials

The prototype was tested in twelve single households for a period of three months. At regular intervals, various mental and physical performance tests as well as life and sleep quality questionnaires were administered. Besides, test persons were encouraged to enter anything they considered worth mentioning and which might affect the outcome of the measurements into personal diaries. We also organized two focus group meetings with our test persons to discuss any issues that might not have been included in the questionnaires or log data. Besides, based on the diaries as well as on information obtained by the coaches that accompanied the test persons during the field trials, case histories have been prepared. These illustrate and convey people's experience with the prototype in a much more accessible way than a list of log data. Case histories can supplement the scientific discussion of the results and are useful for disseminating the results to a wider audience.

The results indicate an overall increase in cognitive performance, in the ability to relax and in overall wellbeing. On the whole, test persons enjoyed the exercises, especially the ones to encourage mental activation. However, they would like to have a bigger choice both with regard to the exercises and the music tunes that accompany the biofeedback sessions.

They found the system easy to handle, appreciated the clear structure of the menus and the simple navigation. The extensive user testing in the development phase obviously had paid off. We can also discern minor improvements in terms of technology acceptance. On the whole, the test persons who evaluated the system in winter and early spring showed a more positive attitude than those using the system in the summer months. This is not surprising since most test persons were active and preferred going for walks outside to watching TV with ALADIN. Quality of life did not seem to have improved significantly which may be due to the fact that most test persons started out from a very high level, so there was little room for improvement.

The evaluation of the field tests, especially the qualitative data gathered by means of interviews and focus group discussions, appears to confirm the contributory factors to user acceptance as outlined before: technology can only complement but never replace interaction with humans and ideally, facilitate human contact. Test persons quite obviously enjoyed the attention they received during the test phase: each test person was assigned a coach who visited them at least once a week. Some of them appreciated the structuring effect that the daily exercises and the regular test runs had on their lives, especially those who had recently retired. These observations have a strong influence on our deliberations regarding ALADIN's future as can be seen further below.

The people who might benefit most, e.g. the fragile, home-bound older elderly, were represented rather poorly in the test population. This is largely due to the selection criteria as well as the recruiting process which relied mainly on traditional media channels. To reach the older elderly, different recruitment strategies would have to be employed such as addressing nursing homes or other care facilities/ organisations. However, this was ruled out by the focus of the AAL programme on independent living. On the other hand, one may argue that older people should familiarize themselves with new technologies that will help them prolong the period they can remain living at home whilst still in comparatively good health and mobile.

One of the basic findings of the field tests is certainly that there is still much research to do. But then, isn´t research all about raising questions and formulating hypotheses rather than finding answers? The real life field testing of the ALADIN provided us with a vast amount of data concerning the factors of well-being and mental fitness in an ageing population and the potential effects of ambient lighting assistance. Even if the sample was small and therefore statistically not significant we gathered very valuable information for advancing the use of lighting for better ageing and improving well-being.

The conclusions which can be derived from the testing in real-life settings can be roughly divided into:

1. Ideas about how to improve the ALADIN prototype and its different components
2. Ideas about how to "package" AAL technology to enhance user acceptance.

3.2 Possible improvements of the prototype

A marketable version of ALADIN is certainly still some years away, but the field test helped us gather many proposals for improvement. Given the open and modular architecture, the prototype and its different components can be easily integrated into general building management systems. Different target groups might be addressed by different functions, modules or components. For example, we have learned that mental fitness training is an activity which appeals to the younger elderly. The automatic lighting adaptation on the other hand helps stabilize the circadian rhythm which is particularly welcome when someone is constrained to such a degree that outdoor activity and thus exposure to sunlight is no longer possible. To reach the fragile elderly, we would have to devise strategies to reach the relevant intermediaries such as health and care professionals, care organizations, building companies and housing associations.

When it comes to the light installation we will have to develop a much cheaper, more stylish and less awesome solution. Besides, older people are very concerned about energy consumption which is why in a future redesign we may consider the use of LEDs. Some minor difficulties with usability and compatibility with home entertainment equipment could be avoided if ALADIN were connectable to any TV set as a plug-and-play device. In this case the remote control could be even simpler.

From the perspective of the test persons the sensor glove was one of the weakest parts of the system, which confirms one of the findings of the requirements analysis that intrusive sensor technology is a crucial aspect of assistive ambient technologies. More effort therefore has to be invested in making the glove even smaller and more ergonomic. Furthermore it should be possible to integrate sensors into the environment intelligently, e.g. a TV relaxation chair or activity chair (for office furniture).

Finally, our results confirmed a basic insight of market research: Products and their features have to give a clearly visible benefit to the customer. In the case of ALADIN it was the automatic light adaptation which lacked this benefit since the adaptation occurred imperceptibly and at a subliminal level. Even if it may be beneficial in the long run, people missed an obvious immediate effect. This may be compensated by adding some features with visible effects such as a light timer to scare off burglars when absent, automatic switch-off as an energy saving measure, automatic switch-on by means of a movement sensor for more comfort, or an automatic navigation help for a safe nocturnal walk to the toilet.

3.3 Improving user acceptance

As said before, the extensive user testing in the development phase has contributed considerably to the user-friendliness of the system – a major prerequisite for user acceptance. User feedback was iteratively incorporated into the system, e.g. the way biosignals are visualised or providing clear status messages. The weakest parts in terms of user acceptance were those that had not been subjected to repeated tests, i.e. the sensor glove which had to be developed quickly as a replacement of the chest belt (which was dropped as a result of user testing). However, what turned out to be more important was the fact that technology would only be accepted if supported and/or accompanied by measures that facilitated social interaction. Based on the findings of our field trials and many discussions we have had with experts as well as representatives of our end-users, the following avenues look promising

3.3.1 Package technology with social support measures

It has been shown clearly that technology can only complement but never replace interaction with humans. Although the great majority of the elderly want to live independently at home for as long as possible, they nevertheless want to be embedded in a social network. In a follow-up project we would like to investigate how this type of support can best be delivered. LMU, for instance, might use SOPHIA, an information and communication platform developed by a housing foundation (Joseph-Stiftung) together with the university and clinic in Bamberg (see www.sophia-tv.de). Via a videophone this ‘virtual nursing home’ connects people to a large variety of health and care as well as social services in the region.

3.3.2 Package technology with advice on ageing-friendly housing

In the course of ALADIN we have acquired a great deal of knowledge about older people’s needs and preferences with regard to housing. Due to mobility constraints, many older people spend a large proportion of their time indoors, which makes optimising lighting so essential for their wellbeing. Lack of daylight may cause seasonal depression and sleep disorders due to irregular circadian rhythms. This can be compensated by longer exposure to light during winter times and higher illumination levels in general since with ageing people’s vision tends to deteriorate. Besides, lights should be dimmable to enable adaptation to the time of day and thus reduce energy consumption.

When installing lighting systems in the homes of the elderly, quantity, spectrum, timing, duration and spatial distribution are important characteristics to be considered. In addition, special age-related impairments such as impaired vision have to be taken into account. In the empirical research for ALADIN, the risk of falling down emerged as one of the most common worries among the elderly. The use of lighting for navigational purposes therefore would clearly respond to older people’s needs. Besides, a future lighting solution would have to address safety and security concerns, e.g. as a protection against burglary or theft.

Another interesting avenue to pursue is the use of light for alleviating mild cognitive impairments such as loss of memory that may signal the oncome of dementia. BLL are collaborating with the Medical University of Innsbruck to investigate how to optimise lighting in this respect. They may prepare a proposal on this topic for the AAL Joint Programme.

In future, we would like to use our knowledge in ageing-friendly housing by joining the growing network of experts and consultants in this field, including the Swiss Centre for Accessible Building (http://www.hindernisfrei-bauen.ch/ or the Sonnweid Foundation (www.stiftung-sonnweid.ch) with a focus on dementia.

FHV, the coordinator, is already involved in a project that aims at developing a housing complex for cross-generational living which includes assistive technologies for an ageing population.

3.4 Conclusions and outlook

The ALADIN system has been found to enhance older people's cognitive performance, their ability to relax and their overall well-being. Given the fact that most test persons had a high level of both mental and physical fitness at the outset of the field trials, the improvements were small, but still measurable. In all future developments that build on the ALADIN project we must emphasise its **USP** (unique selling point), which is **user- and situation-specific personalisation and customisation of room lighting situations**. This is one of the outstanding features that distinguish our solution from the other lighting offerings available on the market. With the ambient lighting solutions available on the market the user has no possibility to interact with the predefined control strategy (mostly defined by the time of the day or the function of the room) and the lighting solutions do not take into account individual and situation-specific differences. Our solution, however, can be tailored to the individuals and their environment by capturing sleep and activity/movement patterns as well as psycho-physiological parameters such as skin conductance or heart rate. For this purpose, we first of all have to further miniaturise the sensor devices and make them more ergonomic, e.g. by integrating them into sleep mattresses or clothing items. By developing an assessment system that captures and analyses the individual and situational differences of the cognitive and affective effects of lighting, ALADIN goes well beyond the current state-of-the art.

Now that the ALADIN prototype is complete and has been tested in real-life settings, the Consortium partners have started looking at opportunities of exploiting the system and its components. The challenge consists in turning research findings into a cost-effective solution that can be marketed successfully to older people across Europe. Anyone who wishes to enhance his or her wellbeing and improve their quality of life by means of intelligent adaptive lighting is a potential customer. There is ample evidence of the economic potential of ALADIN-related research. Europe's population is ageing rapidly. ICT and assistive technologies can help deal with the challenges and opportunities presented by this demographic change. Based on the analysis of published data and demographic trends, we can assume a growing target group of up to 135 millions of European elderly aged 65+ by the year 2050. With an ageing population, the number of people with various physical, psychological or other impairments including chronic conditions such as sleep disorders or various forms of dementia and is expected to rise in all EU countries.

Given the fact, that the average income of the elderly is expected to increase, a host of economic opportunities with great business potential are opening up for age-related products and services, especially in the healthcare field, but also in the housing and building markets. Many houses will need to be adapted to cater for the needs of such people. Homes suitable for older people range from homes that fulfil basic accessibility standards such as no-step entrances and lifts to fully serviced accommodation with care provision. Because the ALADIN system is modular and therefore flexible, it can be implemented in all housing categories. Most of the older adults prefer remaining in their own homes as they age. Residence in a nursing home or care home is not the norm and is often regarded as a last resort. In the Netherlands, for instance, care of the elderly is increasingly moved away from nursing homes (intramural care) into the community (extramural care). In Austria, recent legislation which makes it possible to officially employ informal carers mainly from East European countries has strengthened the extramural trend. From a public policy perspective, this is a cost-effective option provided that the home can be used as a platform to ensure people’s general wellbeing, i.e. the home as a care environment.

So far, intelligent or smart homes have been focusing on building services (heating, cooling, air conditioning, lighting, sun-blinds), household appliances (electric cooker, refrigerator, etc.) and multimedia (telephone, audio and video, TV, etc.) and the associated technological data processing. The integration of human beings by using the occupants’ data - physiological indicators, life style parameters, movement and location, etc. - to assist in their comfort, health and safety has not really been taken into consideration. However, integrating them in future AAL applications would contribute to tailor them to the specific needs, requirements and wishes of particular users. Apart from taking into account psycho-physiological parameters for personalizing technological applications, we are considering other measures for making AAL solutions more attractive and marketable. One of the measures we intend to implement in a follow-up project is to package the technology with support and advice measures.

Although the great majority of the elderly want to live independently at home for as long as possible, they also want to be embedded in a social network. In a follow-up project we would like to investigate how this type of support can best be delivered. One of our partners intends to use SOPHIA, an information and communication platform developed by a housing foundation (Joseph-Stiftung) together with the university and clinic in Bamberg (see www.sophia-tv.de). Via a videophone this ’virtual nursing home’ connects people to a large variety of health and care as well as social services in the region.

Another strategy consists in marketing the ambient lighting solution with a voucher for a certain number of hours for technological assistance. Actually, in many focus group discussions carried out by our colleagues in the social studies department the provision of technical support has emerged as a major prerequisite for user acceptance of new technologies. Most people would be quite happy to pay a higher price provided they are guaranteed a reliable and regular support service, if possible delivered by someone from their own neighbourhood or community. This would be in line with the results of various evaluation studies of patient self-management initiatives (e.g. the Expert Patient Programme in the UK) that showed how important it was that such initiatives be firmly anchored in the community. Since the elderly tend to suffer from chronic conditions to a disproportionate extent, the evaluation results of self-management programs could be very valuable (Jordan and Osborne, 2007; Kennedy et al, 2004).

A further avenue we want to pursue is combining lighting solutions with advice on how to make people’s homes ageing-friendly. In the course of ALADIN we have acquired a great deal of knowledge about older people's needs and preferences with regard to housing. Due to mobility constraints, many older people spend a large proportion of their time indoors, which makes optimizing lighting so essential for their wellbeing. When installing lighting systems in the homes of the elderly, quantity, spectrum, timing, duration and spatial distribution are important characteristics to be considered. In addition, special age-related impairments such as impaired vision have to be taken into account. Therefore the basic ALADIN system will have to be supplemented with some extra functions such as automatic daylight supplement to smoothen contrasts between light and shade or automatic corridor illumination by motion sensors.

In the empirical research for ALADIN, the risk of falling down emerged as one of the most common worries among the elderly. The use of lighting for navigational purposes therefore would clearly respond to older people's needs. Although the lighting industry can already offer a variety of solutions that address safety and security concerns such as recessed LED luminaires along staircases or corridors, few people are aware of their existence. This is why some partners in our consortium are planning to extend their repertoire of services by offering advice and counselling on these issues.

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