What are the Barriers to Efficient Electric Lighting within a Domestic Environment?

In an abridged version of her 2009 dissertation for the MSc Light & Lighting at the Bartlett School of Architecture, Natalia Sokol looks at the main obstacles to energy-efficient residential lighting in both the UK and Poland

Summary

This report presents a study of lighting patterns and the barriers to efficient lighting within domestic environments. It starts from the assumption that implementation of new technologies and energy-efficient lighting solutions in residential dwellings could positively contribute to occupants' well-being and the sustainability of the home environment.

This report looks at the lighting characteristics of 12 dwellings in the UK and 9 dwellings in Poland, with an emphasis on identifying the main obstacles to the implementation of energy-efficient lighting. The pilot study relies on luminance patterns and photographs of kitchens and living rooms in the investigated households – plus occupants' evaluations of visual comfort and lighting preferences obtained via a questionnaire given to 34 subjects. The results of the pilot work laid the foundations for the main experiment, during which a simulation of an energy-efficient lighting scheme was presented and evaluated by eleven subjects. From this data, an attempt was made to identify the main barriers to the development of energy-efficient lighting schemes within residential environments.

Introduction

The purposes of electric lighting within residential dwellings are varied. Light illuminates dark and facilitates a number of activities. Light also provides security and decoration within a dwelling. The number of light points, their types, placement and characteristics, vary within a country and across countries. Occupant behaviour, shaped by demographic and economic factors also plays an important role in defining light settings – as does household typology, size and location within a building structure.

Domestic lighting is also shaped by personal taste and preferences. Personal aesthetics, so difficult to predict or measure, may be determined by a need to emphasise the character of the space (e.g. modern town loft conversion or historic village cottage), institutional recommendations, income, availability of goods and personal situation or style of living. These and other factors form a complex web of issues that directly or indirectly influence residents' decisions – and correlations between type of dwelling, owner behaviour and lighting systems are not easy to assess.

Domestic Lighting and Energy Consumption

Various estimates of the current energy consumed in the residential sector in European Union (EU) countries range from 79 terrawatt hours (tWh) to 97tWh by 2010. The reason for this wide range of figures is the difficulty of obtaining comprehensive data on energy consumption in residential lighting, since this data is not separately measured but estimated using engineering calculations, models and end-user monitoring campaigns based on a sample of households.

Another report estimates average electricity use for lighting in industrial countries, as a percentage of total residential energy, ranges from 10% to 25%; another one estimates that in EU countries lighting constitutes between 6% and 35% of the total residential electricity consumption. In the UK it is 16% and in Poland 28%. The estimated total residential electricity consumption is 111.88tWh in the UK and 22.8tWh in Poland, while average lighting consumption per household per year is 785kWh in the UK and 534kWh in Poland. These figures reflect the different size (square metres) of the household, burning hours and the penetration of energy-efficient lamps in the two countries.

Energy-Efficiency and New Technologies

The primary motivation for increasing energy efficiency in residential lighting is to cut energy use and reduce greenhouse

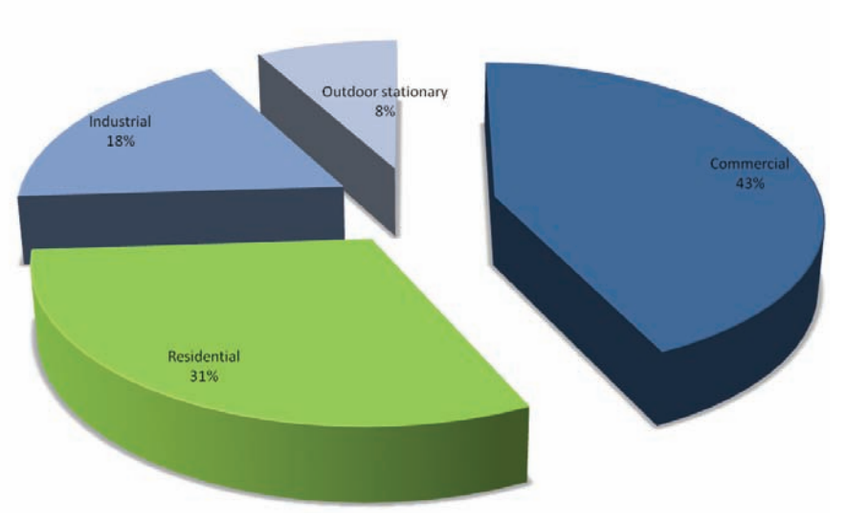
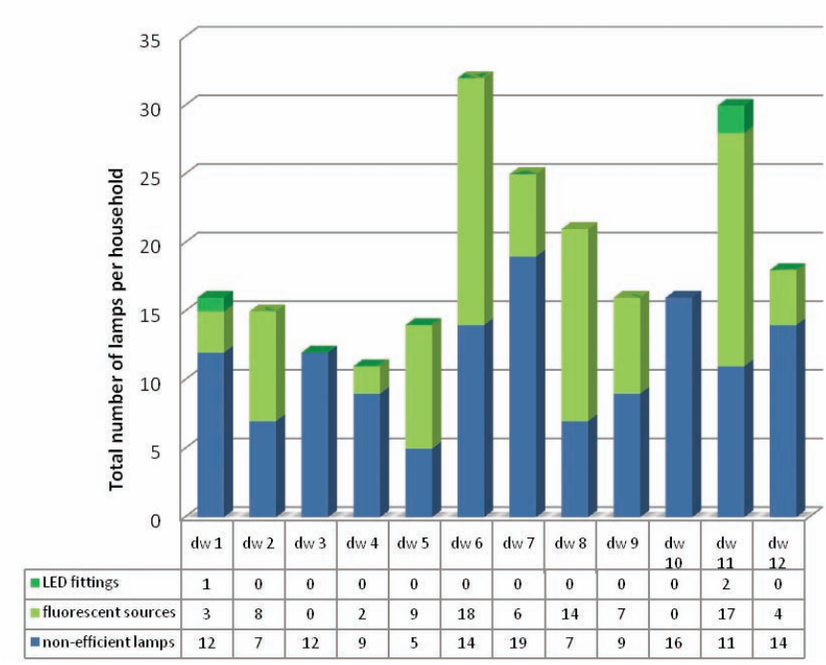


Fig 1: Lighting electricity consumption shares by sector in 2005

gas emissions. One of the ways to increase energy efficiency in domestic lighting is to change from non energy-efficient sources, such as incandescent GLS lamps or high-wattage halogen lamps, to more energy-efficient CFLs or light emitting diodes (LEDs).

It is estimated that in a typical lighting system only 30% of the lumens emitted by the lamp make a useful contribution to the lit environment experienced by its users. Old incandescent lamps have efficacies of 6-18 lm/W and a life of just 1,000 hours. The new technologies in domestic lighting are mainly represented by fluorescent lamps and LEDs. Linear fluorescent lamps (LFLs) have efficacies of 60-104 lm/W. Compact fluorescent lamps have efficacies between 35 and 80 lm/W. CFLs' operational lifetimes are 5 to 15 times as long as incandescent lamps.



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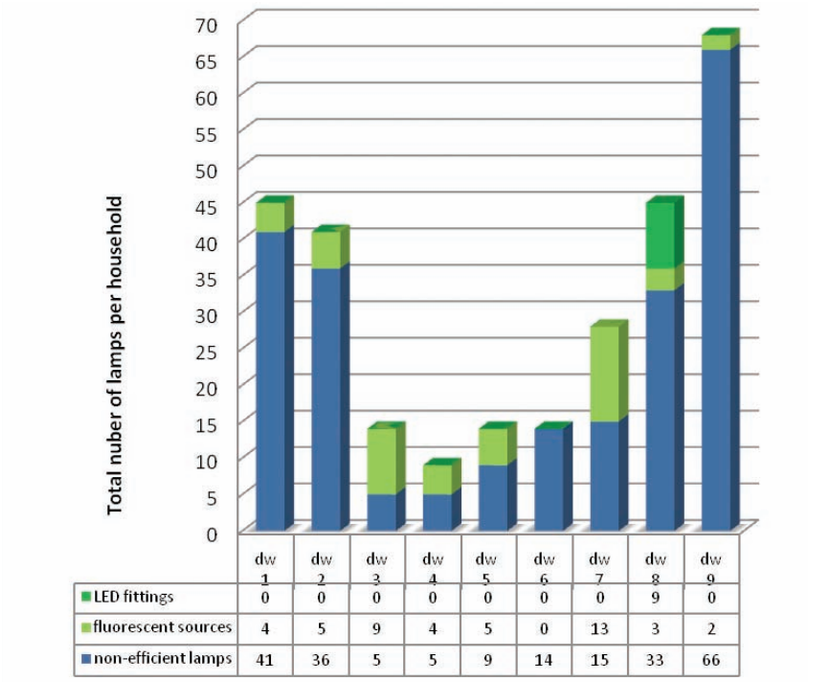
LED fittings	1	0	0	0	0	0	0	0	0	0	2	0
fluorescent sources	3	8	0	2	9	18	6	14	7	0	17	4
non-efficient lamps	12	7	12	9	5	14	19	7	9	16	11	14

Fig 2a: Lamp type breakdown in the 12 UK dwellings surveyed in this study



	dw 1	dw 2	dw 3	dw 4	dw 5	dw 6	dw 7	dw 8	dw 9
LED fittings	0	0	0	0	0	0	0	9	0
fluorescent sources	4	5	9	4	5	0	13	3	2
non-efficient lamps	41	36	5	5	9	14	15	33	66

Fig 2b: Lamp type breakdown in the 9 Polish dwellings in this surveyed study

Solid-state lighting (SSL) devices like white-light-emitting LEDs currently have efficacies of 50 lm/W (2009). However, due to the rapid development of this technology, the SSL industry aims to achieve efficacy levels up to 200lm/W. All the sources have disadvantages and advantages but it is worth remembering that the global demand for artificial light has also been growing at an average rate of 2.4% per annum. The use of new technologies can help to save electricity and therefore reduce the overall cost of lighting.

Compared with incandescent technology, the 3.5 billion CFLs in use today save 229tWh of electricity annually. If all incandescent lamps worldwide were replaced by CFLs, an additional 728tWh of electricity would be saved per annum and global lighting energy demand would be reduced by 27%. Yet the number of CFLs per household in the UK only ranges from 0.7 to 2. The total number of households is 22.8 million; while in Poland, the number of CFLs per household is estimated to be 0.5 (13 million households).

Residential Lighting Standards

People spend a large part of their lives at home. Home is considered a private space, where people relax, work, socialise and practice hobbies. A variety of different tasks carried out at home require multi-functional lighting schemes. A home often appears as a space where it is difficult to apply uniform lighting rules to fulfil occupants' needs. Consequently, there is a deficiency, and wide range, of residential lighting recommendations and legislation across Europe.

Moreover, recommended lighting levels have changed substantially over the years. Guidelines published by CIBSE SLL in *Lighting Guide 9: Lighting for Communal and Residential Buildings* recommend values for different tasks. For instance, 200 lux is recommended in a kitchen and 100 lux for circulation areas and corridors – 200 lux is also proposed for typical student rooms in educational buildings. In Poland, although offices and other types of commercial interior lighting are subject to standards, in general there is very little guidance for residential lighting schemes.

Residential Lighting Design and Luminaires

Residential lighting is an area that requires cooperation between the various parties involved in the design of residential dwellings – but this cooperation is rarely forthcoming. The electric installation designed by the electrical engineer often dictates the lighting solutions. Usually, the lighting scheme is the last issue to worry

about and it is often decided by coincidence or 'common knowledge'. Seldom is residential electrical lighting studied thoroughly and designed in conjunction with daylight or future interior design. Therefore, most occupants are forced to deal with a ready-to-use lighting installation and have to adjust it to their personal needs, using ideas from friends' apartments, colour magazines or commercial guides published online by lighting companies. End-user decisions are often limited merely to a choice of lamp types and their housings.

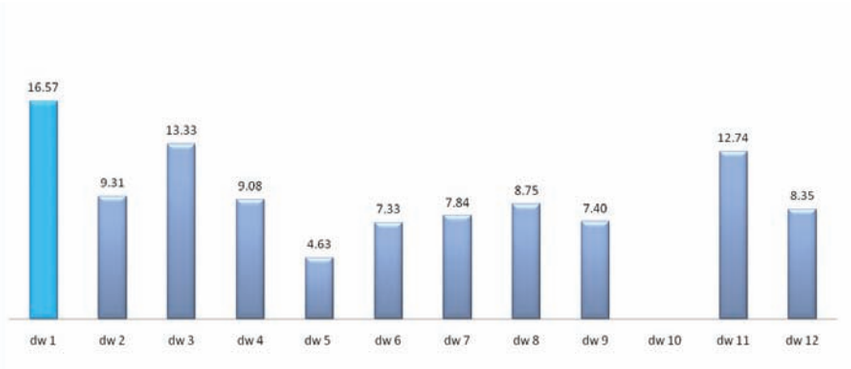


Fig 3a: installed W/m^2 in the surveyed British dwellings

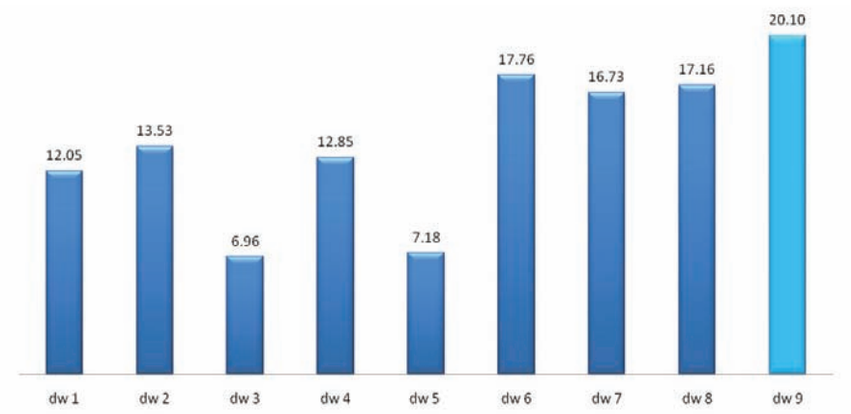


Fig 3b: installed W/m^2 in the surveyed Polish dwellings

Typical UK living room lighting (left) and kitchen (right) from the study

Neither are most residents aware of the percentage of the total home energy consumption accounted for by lighting. Residents have some knowledge of traditional lighting solutions and sources, like GLS lamps, but most have little knowledge of new energy-saving solutions, which makes them reluctant to install efficient lighting sources.

A choice of quality luminaires with suitable photometric data is important in creating any successful and efficient lighting scheme. However, in residential lighting, such luminaires are mainly installed in the houses of high-end users. The majority of occupants install fittings from the cheaper mid-range where no photometric data is available. Therefore, choices of decorative luminaires are based partly on aesthetics and partly on the properties of the lighting source, which comes with the fitting. Often the lighting fitting is treated as an element of interior decoration, which also happens to illuminate the space during the evenings.

Alternatively, the fitting is only perceived as a housing for the light source and the 'lighting design' is simply based on changing lamps with different photometric properties. According to the literature, the most common light source installed in European homes – including the UK and Poland – is still the incandescent lamp (GLS).

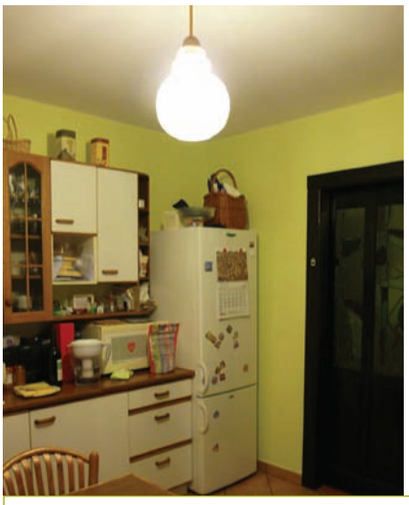
Tenure

The choice of lighting also depends on an occupant's relation to the dwelling. Figures suggest that 70.1% of houses in the UK in 2006 were occupied by owners or share owners and long leaseholders – and 26% of dwellings were rented. The rest included private renting and local authority tenants.

In Poland, tenure relationships are complex. According to the Polish Central Statistics Office, the dwelling stock (2007) amounted to 13 million dwellings, of which 45.6% are owned by housing cooperatives. These are followed by dwellings in condominium buildings (33.3%), municipal dwellings (16.8%), company dwellings (2.3%), public building societies dwellings (1.0%), and dwellings owed by the State Treasury (0.9%).

Barriers

According to a literature review, the main barriers to energy-efficiency in lighting are: lack of information about lighting; scepticism about new technologies among building managers, architects, designers and end-users; the higher purchase cost of energy-efficient light sources; the current state of technology development;



Typical Polish kitchen lighting set-up (left) and living room (right) from the study

customer ignorance about pay-back periods; quality issues with CFLs (aesthetic, colour temperature, slow time delay to full output); customer mistrust of CFLs due to early failures; and a recent increase in the use of low-voltage halogen lamps and double-ended high voltage lamps.

One other important barrier is the separation of capital expenditure and operating expenditure, with developers and property owners most interested in lower initial capital costs, which often means less efficient lighting systems being installed. Tenants or purchasers are then forced to pay the higher costs of operation.

The Study

Twelve dwellings in the UK and nine dwellings in Poland were studied, using a variety of research techniques:

- Subjective assessment of the existing lighting done by reviewed occupants in their dwellings, via a questionnaire to 17 subjects in each of the two countries, with a wide range of occupations, age-groups and daily dwell-time in the home.
- Visual assessment of the photographs
- Illuminance level measurements
- Objective assessment of results of luminance pattern measurements
- Statistical analysis of the findings

Following the pilot study, 11 subjects (six women and five men) who had taken part in the pilot study, agreed to participate in the second phase of the research, which involved their subjective assessments of an energy-efficient scheme created in the living room of one of the homes concerned. Eleven subjects were asked to perform three different tasks: writing, reading and watching TV under two different lighting schemes, namely the existing scheme, using mainly GLS (total energy consumption, 250W) and a new energy-efficient one based on CFL and LED luminaires (total energy 113W) provided by Philips Lighting. At the end of each lighting sequence, the subjects were asked to fill out a questionnaire assessing their preferences and lighting comfort during the performed tasks.

Selected Findings from the Survey

- Only two subjects from the UK and five subjects from Poland were involved in designing a lighting scheme for their homes.
- The average number of efficient lamps (CFLs and LFL and LEDs) in the British dwellings was 8.3; and in the Polish dwellings it was 6 per household.
- The average size of the examined dwellings was the same, at 83m^2, in both the UK and Poland (although national statistics suggest that UK homes are on average 22sq.m. larger in area than Polish dwellings).
- The average installed wattage per square metre in the UK was 9.8 while in Poland it was 13.8.
- 24% of the British respondents never changed the lighting in their homes; 23% of the subjects changed the lighting one a year or once every five years; 18% changed the lighting when they were moving.
- 41% of the Polish respondents never changed their lighting; 6% of the subjects replaced the lighting once every three years; and 5% once every five years; 35% of the occupants changed the lighting when they moved home.
- Eight of the 17 British subjects had no idea how much home energy consumption the lighting constituted. Other respondents cited figures from 8% to 95%.
- Eight of the questioned Polish subjects had no idea how much home energy consumption was taken up by lighting – on average they estimated some 31%.
- Ten of the 17 British respondents left the lights on when leaving a room; three Poles shared this habit.
- The most sought-after feature of the lighting schemes in the UK was 'to be functional' followed by 'to be cosy and pleasant, and 'to create a nice atmosphere' and 'to be energy efficient'. In Poland, the most expected features were 'to be cosy and pleasant' rather than 'to be functional'.
- Fifteen subjects form the investigated group showed a preference for 'warm' lighting.
- According to the British subjects the main problem with fluorescent light was its 'wrong colour', mainly it was 'too cold' (8 people) and 'too dim' (4). According to the Polish respondents, the main problem with fluorescent light was its 'wrong colour' and being 'too cold' (7) and 'too dim' (3). The next most popular comment about CFLs was the 'delay with light output' (10 answers in the UK and 9 answers in Poland).
- Knowledge about LEDs was minimal among those surveyed, with only two subjects using them. Despite the lack of experience with LEDs 20 occupants would consider installing them in their houses.
- In terms of UK respondents' comments about LEDs the most frequently chosen was 'wrong colour of light' – 'too blue' was the most common comment. Eight UK respondents chose 'problems with light output' and 'not enough light'. Seven respondents highlighted 'too high purchase price', 'problems

Fig 4: Philips Ledino pendant used in the experiment

Fig 5: Philips Ledino desk light used in the experiment

with quality' and 'the need to buy new fittings'. Polish subjects pointed out a 'lack of information about new sources' and 'too high purchase price'.

- Despite International Energy Agency figures stating that the majority (53%) of residential lighting worldwide is provided by fluorescent lighting, this research confirms that most of the British and Polish dwellings lighting schemes are based on GLS lamps.
- The majority of the investigated dwellings had luminaires of at least five years old or older which were designed for use with non-efficient lamps – and 82% of the investigated schemes demonstrated the need to be updated.
- Houses built in the last five years were often fitted with recessed incandescent fixtures, which were very difficult to modify without major renovations.

Selected Findings from the Low Energy Installation Study

- For the writing task, the LED-based scheme provided the best lighting conditions and it was definitely preferred by the subjects. The preferred working plane luminance was 40cd/m^2; and the preferred wall luminance range was 10–30cd/m^2. The illuminance measurement taken at the writing surface showed 200 lux.
- The respondents described the LED fitting as better designed than the halogen fitting, with the light spectrum closer to daylight and glare free.
- For reading, both halogen floor and LED table fixtures provided good lighting, but LED lighting was preferred. The preferred task surface luminance was 20–36cd/m^2 and the wall luminance was10–30 cd/m^2. The illuminance values at the reading surfaces were 100 lux or 140 lux.
- For the third activity, TV viewing, the conditions provided by an energy efficient scheme were worse than the conditions provided by an existing scheme, with the ambient light (luminance range 10-30cd/m^2 on the walls) being too high for TV viewing. The observers demonstrated a preference for the existing scheme (the main surface luminance was 10–20cd/m^2).
- In UK kitchens, the leading trends were to provide general ambient lighting mostly with ceiling recessed fittings – while Polish kitchens relied on suspended fixtures with one lamp.
- Task illumination was provided by fluorescent lamps fitted under cabinets in the UK – and GLS or halogen lamps in Poland.
- In the investigated kitchens, British kitchen lighting schemes were better designed, more uniform and more efficient than the Polish ones.
- Most of the Polish and British respondents appraised the lighting in their kitchens as 'good' or 'very good' and were happy with its light output and uniformity.
- Living room lighting schemes were based on a combination of ambient light from a main lighting source, usually a suspended fixture with three to five lamps, plus light provided by additional sources installed on walls, tables or by floor fixtures.
- Eighteen respondents assessed the lighting in their living rooms as not good or even poor.
- One interesting finding was that occupants introduced to new technology showed considerable interest, with six subjects deciding to install LED fixtures in their homes in the near future.

Conclusions

Drawing on the findings of the pilot work and the visual demonstration, we can identify a number of major barriers to the adoption of energy-efficient lighting schemes within a domestic environment:

- Lack of motivation: most of the users are time-constrained. Optimising working lighting schemes is often the last issue on their agendas.
- Financial issues: investing money in energy-efficient sources and more sophisticated luminaires, which are more expensive, are often impossible, especially where the number of lighting points is significant.
- Lighting technology imperfections: wrong colour of CFLs and LFLs. Respondents pointed out uncomfortable light: not warm enough; delay with light output; low quality of the CFLs.

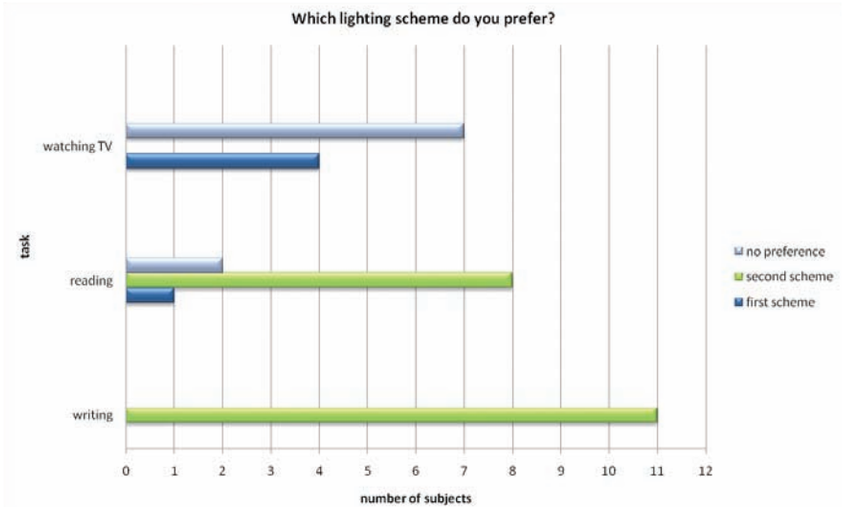
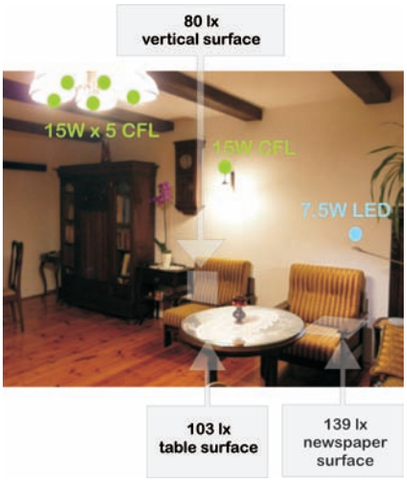


Fig 6: Interviewees' preferences for the two schemes across the three visual tasks



The new lighting for the reading task showing lux levels

- Lighting scheme decided by developer: lack of influence on lighting scheme and unreachable lighting points
- Rental agreement: the landlord/tenant discrepancy of interests – the tenants' hands are often tied and requests to make changes in inefficient lighting schemes are often unanswered. On the other hand, property owners are only interested in making changes that boost their profits.
- Lighting market imperfections: the initiatives to transform the lighting market and to provide occupants with information about the energy-efficiency of new lamps, are struggling to succeed.

The barriers to energy efficient lighting penetration in British and Polish homes are similar to those outlined in the relevant literature. The pilot work's objective analysis proved that lack of interest in lighting per se is one of the greatest barriers for any change within a typical household, especially the implementation of new technologies.

The experimental implementation of new technologies in a residential environment demonstrated that, informed and equipped with knowledge and experience, observers were willing to invest in new technologies, in this case LEDs. The subjects saw advantages in the new lighting schemes and were willing to adopt them, but only if the proposed schemes were suitable to their needs and were better than the old ones. The main barrier was the lack of knowledge and information/experience about new technologies among lighting users.

The occupants did not show any resistance to new technology. However, they commented on the difficult access to replace components in the case of a fixture failure. In addition, financial concerns were raised. The prices of LED fittings were estimated to be five times higher than the prices of similar fittings from decorative ranges fitted with GLS.

Recommendations for Different Domestic Areas

According to this study of existing lighting conditions in kitchens, schemes based on one centrally suspended fixture with GLS sources or ceiling-recessed fixtures, cannot accommodate occupants' needs nor fulfil energy-efficiency goals. The kitchen area needs uniform task lighting, and adequate ambient illumination, which can be provided by energy-efficient sources with good colour rendering properties. Polish kitchen schemes should open up to new lighting techniques, including the use of modern LCLs and LEDs. More energy efficient sources should be applied in British kitchens to replace ceiling-recessed 'cans' with incandescent lamps.

Living room lighting schemes should address the flexibility issue better. Adequate illumination levels on the horizontal and vertical surfaces for different activities would accommodate users' needs more fully. The idea of different layers of light seems to be a good opportunity for applying new technologies including movable light fixtures with adjustable sources, which would provide localised lighting for particular tasks, while contributing to the overall ambience of the area.

General Policy Recommendations

There have been various initiatives to overcome the barriers to energy-efficient lighting by different international and governmental institutions. Firstly, there is no doubt that there should be some national controls or standards for residential lighting energy efficiency. In the UK Part L regulations for new and refurbished residential schemes are already in place – and were recently made more stringent – but there are no standards covering existing residential lighting.

Wide-spread awareness campaigns, voluntary actions, international agreements and mandatory standards could go some way to combat the various obstacles, providing the main issues are addressed and all parties involved are willing to cooperate.

There has been also a lot of debate about the EU ban on inefficient incandescent lighting, based on a step-by-step plan to phase them out in stages. The proposal was seen as controversial by people involved in residential lighting as well as by end-users. Over 70% of those interviewed in this research would not welcome bans on non-energy efficient sources. However, they wished to be more informed about the alternatives to inefficient sources.

To tackle the barriers identified during this research will require many changes on a global basis, involving manufacturers, regulatory bodies, campaigning organisations and lighting designers – as well as much more sophisticated research. However, in the long run residents themselves will have to make the final decisions concerning the use of light sources and luminaires in their homes. To do this they should have easy access to new technology and adequate information to make the right choices. ***For more information contact*** **natalia.sokol@gmail.com**

The new lighting for the writing task showing lux levels