

# End-use analysis on domestic lighting

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## KEYWORDS

domestic lighting, end-use analysis, monitoring, compact fluorescent lamp, DSM-programmes, barriers, dedicated luminaires, design competition, lighting pattern

## ABSTRACT

The use of compact fluorescent lamps (CFLs) leads to sizeable reductions in energy consumption. Most existing and coming countries in the European Community are or have been promoting the use of CFLs. Although good results have been achieved, the potential for savings in the EU is evaluated to be at least four times the realised!

Marked studies have been executed in order to find the worst barriers and how to convince customers of the benefits of using CFLs in stead of incandescent lamps. In Denmark, these studies are recently supplied by mapping which lighting sources are actually installed in 100 Danish homes. By recording the energy consumption every 10 minutes for 20 lamps as well as the total lighting consumption, the use of the single lighting source in each of the 100 homes can be analysed. This is resulting in a huge amount of end-use lighting data.

A detailed energy analysis is presented, including electricity consumption divided into incandescent lamps, halogens, linear fluorescent lamps, and CFLs, use of lighting sources divided into wattages as well as per type of room in the home. These results are related to marked research results from a recent SAVE dissemination study as well as results from the large Danish CFL campaigns performed during the last two winters. The potential for more energy efficient lighting will be evaluated, taking into account the already established use of energy efficient lighting.

Finally, short-term avenues for increased use of CFLs will be summarised. This is followed by long-term avenues, including use of dedicated fixtures/luminaires where interaction between the bulb and fixture/luminaires will result in better quality in light distribution. Relations to the actual European Lighting Design Competition "Light of the Future" are drawn.

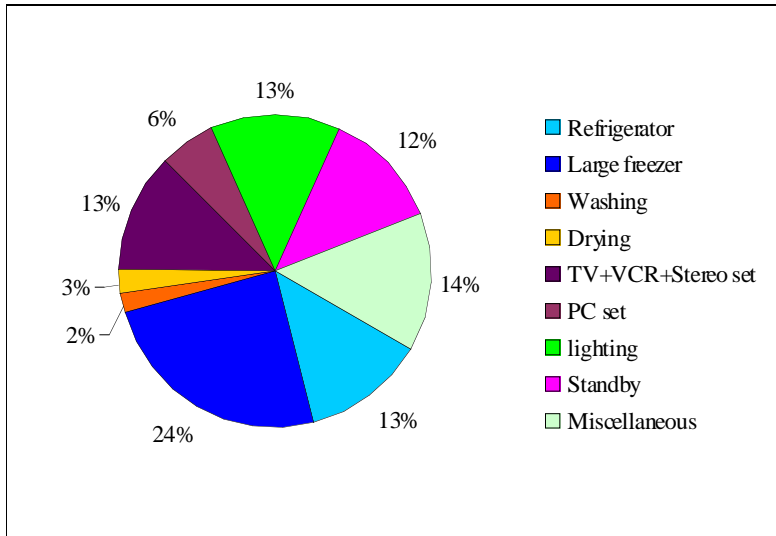
## INTRODUCTION

During more than ten years, many DSM programmes around the world have been carried out to encourage customers to use CFLs in stead of incandescent lamps. These programmes include different combinations of rebates, give-aways, wholesale discounts, pay-on-the-bill schemes, and direct installations. A very broad range of promotional strategies has been employed, including direct mail, advertisements in newspapers, brochures, TV and radio commercials/announcements, and articles.

The European Union's SAVE programme has supported several projects, [1], [2], and [3], to gather more knowledge about the residential lighting saving potential and the market situation for CFLs. Besides this, the EU has taken three initiatives,

- Implementation in 1998 of a directive on energy labelling of household lamps
- Launching two major European luminaire design competitions for energy-efficient lighting fixtures in the residential sector. The first competition was running in the period autumn 1999 – Spring 2000. While the winners of the second competition will be published at the Light+Building fair in April 2002 [6].

Figure 1. Example of mapping of the end-use consumption in one home



- Autumn 1999, EU and UNIPED/EURELECTRIC have launched a European umbrella campaign to promote CFLs. This includes a quality charter and collecting of results [5]. An updating of the quality charter started March 2002.

In 1999, a strategy study on promotion of energy efficient lighting in IEA member countries was performed [4]. This found a substantial energy efficient lighting potential. Six political short-term avenues for IEA were described. Programmes for other parts of the world, e.g. ELI, including countries from Eastern Europe, Africa, and South America, is also dealing with promotion of energy efficient lighting [7].

Marked studies have been executed in order to find the worst barriers and how to convince customers of the benefits of using CFLs in stead of incandescent lamps. In Denmark, these studies are recently supplied by mapping which lighting sources are actually installed in 100 Danish homes as well as mapping the behaviour of using the single lighting source by recording the energy consumption every 10 minutes for 20 lamps as well as the total lighting con-

sumption in each of the 100 homes, resulting in a huge amount of end-use lighting data.

This paper is giving results from a detailed energy analysis, including division into incandescent lamps, halogens, linear fluorescent lamps, and CFLs.

**END USE RECORDING IN 100 HOMES**

The SAVE project EURECO, finalised by the end of 2001, studied end use consumption in the home. End use load recordings have been taking place for at least one month/home in 100 Danish homes supplied by a utility in Odense. An example of mapping of the consumption per end-use is shown in figure 1.

The 100 Danish homes included,

- 85 detached houses with an average area of 139 m<sup>2</sup>, 3.2 persons/home and an average consumption of 3.764 kWh/year
- 15 flats with an average area of 90 m<sup>2</sup>, 2.3 persons/home and an average consumption of 2.039 kWh/year

The left side diagram in figure 2 shows the lighting consumption in percentage of the total consumption per house. The right side diagram shows the average percentage per month. As the recording is spread only on ten months, January is assumed to be like November and February is found by interpolation between January and March.

The monthly average lighting consumption varies between 5% and 21% of the total respective monthly consumption. Although the lighting consumption is higher in winter, the above figures indicate that the lighting takes less than the standard value 20% of the yearly domestic consumption. This may be due to more use of energy efficient lighting.

Recording the energy consumption every 10 minutes for 20 lamps as well as the total lighting consumption in each of the 100 homes makes it possible to find the behaviour of using each single lamp. This has produced a huge amount of end-use lighting data. Figure 3 gives an example of a pattern of use of lighting for one home during one week in August.

Figure 2. Lighting in percentage of the total consumption

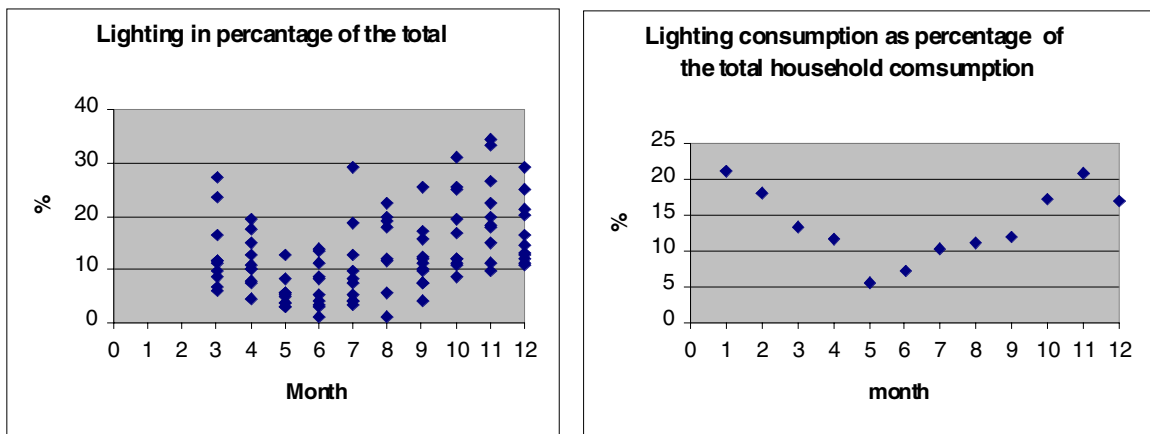
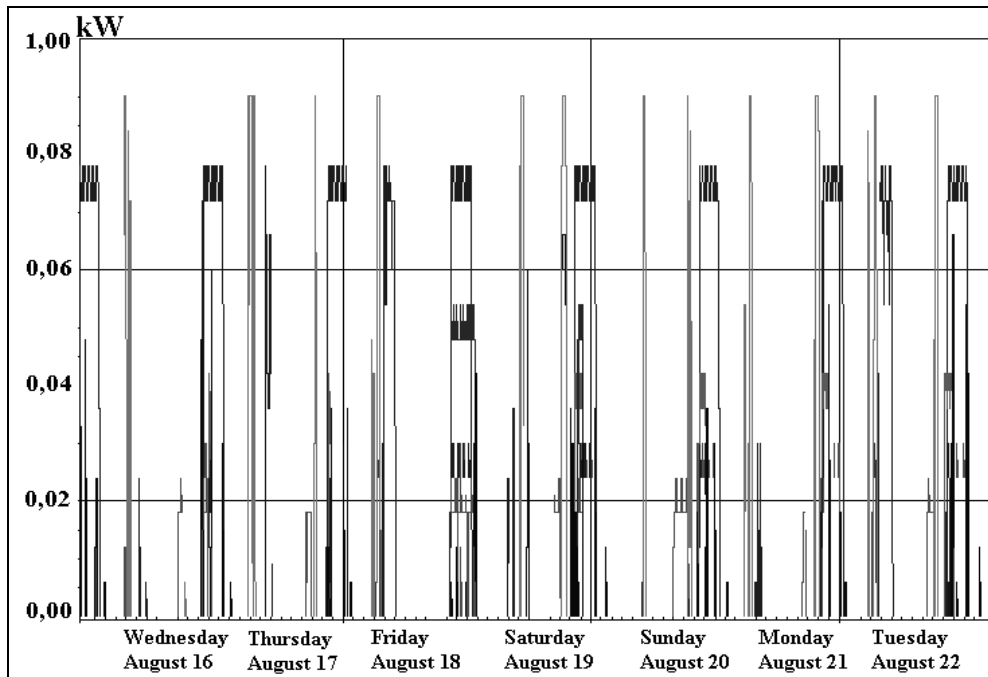


Figure 3. Use of 12 lamps during 8 days.



**USE OF DIFFERENT TYPES OF LIGHTING SOURCES**

Mapping of the use of lighting sources in the 100 homes gave the total numbers of lamps shown in table 1.

Table 1. Use of different lighting sources

Lighting source	Number	%
Incandescent lamps	1475	56
Halogen lamps	537	20
Linear fluorescent lamps	224	9
CFLs	399	15
Total	2635	

Figure 4. Use of incandescent lamps divided on wattage

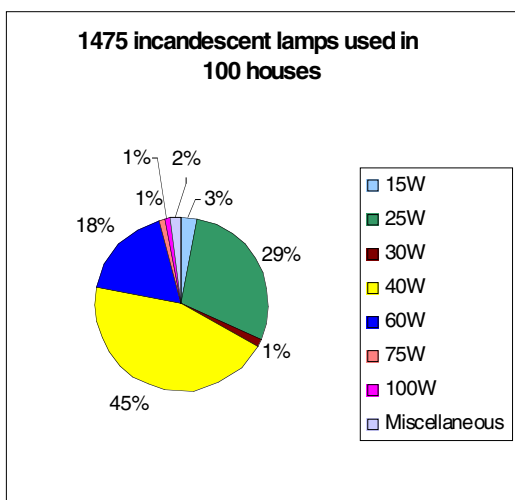
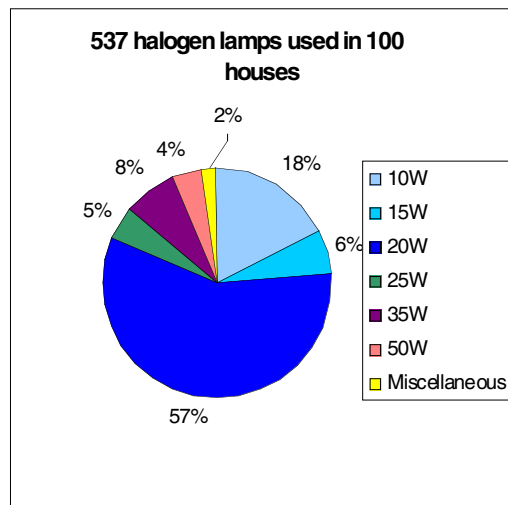


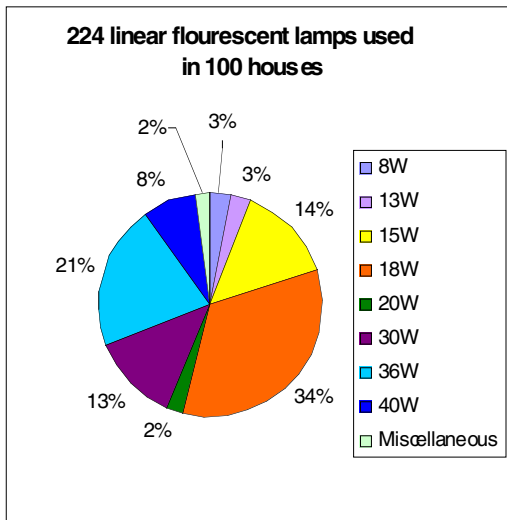
Figure 5. Use of halogen lamps divided on wattage



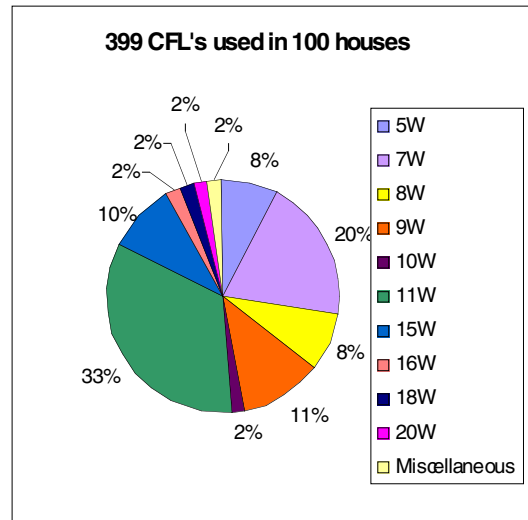
In average, 26.4 lighting sources are thus used per home where 6.1 or 24% of the lamps are energy efficient lamps.

Figure 4 shows a break down of the 14.8 incandescent lamps/home by wattage. 40W is the most common lamp with 45%, followed by 25W with 29% and 60W with 18%. It is surprising to see 78% of the lamps have lower wattage than 60W. Figure 5 shows a break down of the 5.4 halogen/home lamps by wattage. Although halogen lamps are introduced later on the market than CFLs, they are already at a higher number than CFLs. This may be explained by new lighting possibilities with halogens while the reasons for use of CFLs are at present only economical and environmental. 20W is the most common lamp with 57%, followed by 10W with 18% and 35W with 8%.

**Figure 6. Use of linear fluorescent lamps divided on wattage**



**Figure 7. Use of CFLs divided on wattage**



**Figure 8. Number of lamps and installed wattage per type of room**

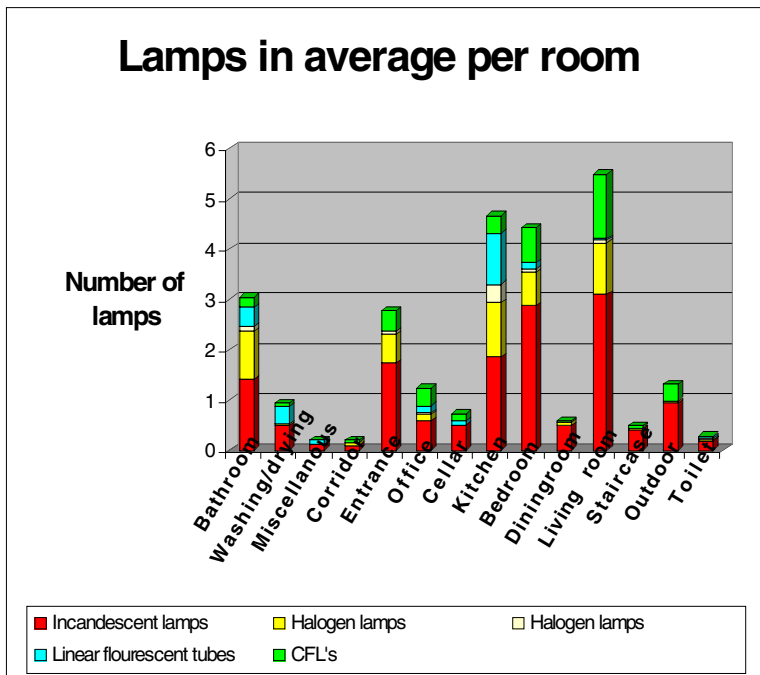


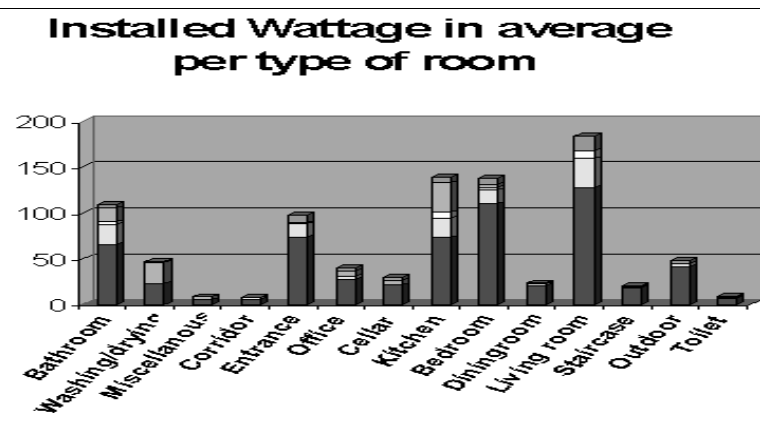
Figure 6 shows a break down of the 2.2 linear fluorescent lamps/home by wattage. 18W is the most common lamp with 34%, followed by 36W with 21%, 15W with 14%, and 30W with 13%. 80% of these lamps have a wattage of 18W or more. Figure 7 shows a break down of the 4.0 CFL/home by wattage. 11W is the most common lamp with 33%, followed by 7W with 20%, 9W with 11%, and 15W with 10%. Half of the CFLs have a lower wattage than 11W which might be due to the fact that manufacturers primarily market products with lower wattage than 15W and their inadequate information on wattage comparison between incandescent lamps and CFLs leads to too small wattage.

**USE OF LIGHTING PER ROOM IN THE HOME**

Figure 8 shows that most lamps are installed in the living room, kitchen, and bedrooms. Other results are,

- Incandescent lamps are used in all types of rooms
- Halogen lamps (divided into low voltage and normal voltage) are used in bathroom, entrance, kitchen, bedroom, and living room
- Linear fluorescent tubes are primarily used in kitchens, followed by the washing/drying room and bathroom
- CFLs are primarily used in the living room follow by bedroom, entrance, kitchen, outdoors, and office.

**Figure 9**



**THE SHARE OF LIGHTING CONSUMPTION PROVIDED BY ENERGY EFFICIENT LAMPS**

An analysis of the lighting consumption in the 100 homes gives the results presented in table 2. Incandescent lamps takes 63% of the consumption while it is in number only 56% of the lamps.

**Table 2. Lighting consumption and lighting sources**

Lighting source	Number in %	Lighting consumption %
Incandescent lamps	56	63
Halogen lamps	20	16
Linear fluorescent lamps	9	11
CFLs	15	11
<b>Total</b>	<b>26,4/home</b>	

Figure 10 shows the lighting consumption in percentage divided into the four types of lighting sources for the 100 homes.

On the left side can be seen some homes with almost only incandescent lamps while the homes on the right side primarily use energy efficient lighting.

Concerning figure 11 is found,

- In 12 of the homes more than 50% of the lighting consumption comes from energy efficient lighting (linear fluorescent lighting and CFLs)
- In 34 houses more than 25% of the lighting consumption comes from energy efficient lighting.

Looking at the 12 homes (including 11 detached houses and 1 flat) with more than 50% of the lighting consumption taken by energy efficient lighting gives the following characteristics,

- The average area 96 m2 is smaller than the average 118 m2 for all 100 homes.
- The number of persons 2.2 is smaller than the average 3.1 for all the 100 homes. Four of the homes have only one person living there, which is a high proportion in relation to the 100 homes only including 8 homes with 1 person living there.
- The average yearly consumption 3.091 kWh against 3.505 kWh for all 100 homes.

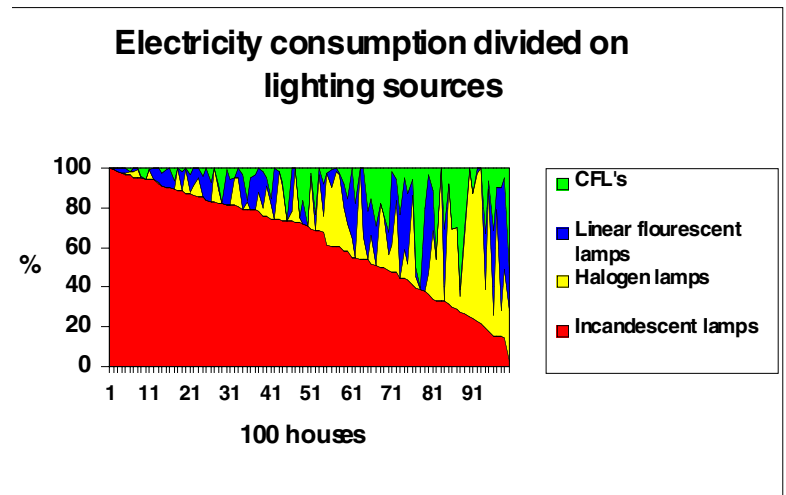
Figure 12 shows that,

- In 8 of the homes more than 50% of the lighting consumption comes from halogen lighting.
- In 26 houses more than 25% of the lighting consumption comes from halogen lighting.

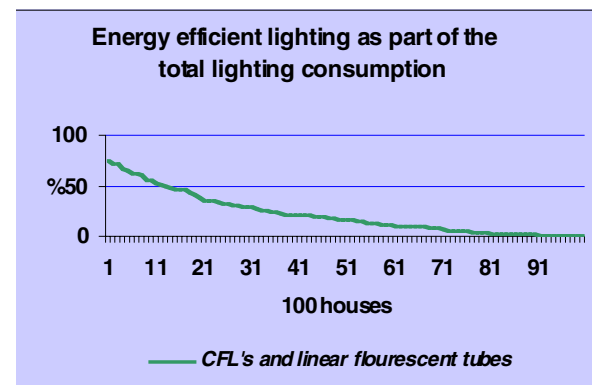
Looking at the 8 homes (including 6 detached houses and 2 flats) with more than 50% of the lighting consumption taken by halogen lighting gives the following characteristics for these homes,

- Average area 129 m2 larger than the average 118 m2 for all 100 homes.

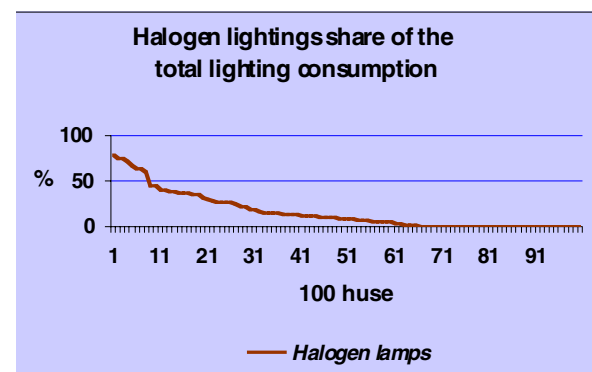
**Figure 10. Consumption divided on four types of lighting sources**



**Figure 11. Energy efficient lighting's part of the lighting consumption**



**Figure 12. Halogen lighting's part of the lighting consumption**



- Number of persons 2.6 smaller than the average 3.1 for all the 100 homes.
- Average yearly consumption 3.067 kWh against 3.505 kWh for all 100 homes.

### POTENTIAL FOR FURTHER ELECTRICITY SAVINGS BY ENERGY EFFICIENT LIGHTING

Load recording of the user pattern for every lamp in every home along with information about the placement of each lamp forms a basis for an exact calculation of the consumption and hours of use for each lamp. It is then possible to evaluate where it is possible and economically justified to replace the existing lamps by energy efficient lighting sources. These comprehensive calculations including around 2.000 lamps are not performed yet due to lack of funding for this analysis.

The luminous efficacy and thus the energy efficiency for fluorescent lighting sources is at least four times better than for the incandescent lamp. From an economical point of view, the potential is dependent on the following factors,

- Prices for a CFL and for an incandescent lamp
- Electricity price
- Lifetime of the type of the CFL
- Burning hours per lamp and year

The price of CFLs has constantly decreased during the last years while the number of people owning CFLs has increased. The CFL price in the furniture store IKEA is now down at 3 Euro in many countries and after the last large campaigns the Danish average price has decreased from 11 to 7 Euros. The market is still inhomogeneous with prices from 2 to 16 Euros.

The electricity price for residential customers has increased in several countries due to increasing GHG taxes. In Denmark, more than 66% of the residential electricity price is taxes for the state.

The lifetime of CFLs has been increasing to 10-12.000 hours for the finger type while it is only half this size at 5-6000 hours for the look-a-like type.

The burning hours per year determine how quick the CFL investment is paid back. In Denmark the payback time is now only around one year for a lamp only burning 1 hour per day!

The BCR (Benefit Cost Ratio) is very favourable both for the customer and for the society in nearly all countries with BCR values often very good at 5 or more.

The SAVE projects [1] and [2] have found that there is at least room for 8 CFLs per home. In Denmark more than 3 CFLs is now used per home. Around 2/3 of the population own CFLs which means these people are using around 4.5 CFLs per. home. The 100 homes in the above analysis are in average using 4 CFLs, where 93% are owners of CFLs and the owners are thus having 4.3 CFLs/home, which is in good harmony with the general Danish situation.

A SAVE study from 2000 [3] found 39% of the people in the extended EU own CFLs and these owners have in average 3.4 CFL/home. This equals an average of 1.3 CFL/home for all EU households. This study [3] found that an increase from 1.3 to 8.0 CFLs would give a 6.9% reduction of the total residential electricity consumption which again is equal to a little over 1.9% of the total electricity consumption for these countries!

### SHORT TERM AVENUES FOR MORE USE OF ENERGY EFFICIENT LIGHTING

During the last two winters, the Danish Electricity Saving Trust and the Danish utilities campaigns with great success have been focusing on price and quality by co-operation with the retail market and publishing a list of A-lamps on the internet, including CFLs fulfilling the requirements in the EU/EURELECTRIC quality charter [5] along with information of the price in shops selling these. This has proven an efficient method although several manufacturers and market chains did not want to join the list.

As the price has fallen this barrier for buying is not so high any longer. It seems more important to avoid low-quality products by having a public laboratory to do quality testing as it is performed in Denmark.

Some people are complaining that "CFLs do not give good lighting" where they mean enough lighting. This is due to the fact that manufacturers are not giving correct information about replacement of incandescent lamps by CFLs in order to have the same amount of lumen. This problem grows with the life of the CFL because the lumen output decreases exponentially. A customer replacing a 60 W incandescent lamp by an 11 W CFL loses nearly 20% lumen output! It would be better to give a positive experience of having an extra lumen output, e.g. by replacing a 60W incandescent by a 15W CFL. Danish utilities and public bodies are giving correct information about how to replace but unfortunately this is conflicting with information on the packaging of the CFLs. It is the hope that information on how to replace will be included in the 2002 revision of the quality charter.

Many studies have shown that there is a great need for better customer information, especially in the buying situation.

This can be improved by demonstration of the CFLs in the shops, education/information for shop assistants, warranty concerning lifetime and payback over the electricity bill e.g. by use of coupons bought at the utility for use in the shops. It is preferred to inform by pictures with as little text as possible.

Powerful marketing requires that all stake holders co-operate and co-ordinate the marketing. The author recommends mapping the barriers existing in the country and selecting a few most important. Hereafter it is recommended to find a good marketing story and do the marketing consistently with co-operation between all stake holders: CFL manufacturers, fixture manufacturers, retailers, designers, utilities, government agencies, non-government organisations, and customers' organisations. Marketing has to be accompanied by evaluation of how lighting is used, who purchases CFLs, and who do not (different kind of segmentation), attitudes relevant to choice of light source, and barriers which appear.

A goal is to get a CFL into every home because when the first CFL get in to the home, then the number of CFLs tends to increase during the next years. In the period from 1996 to now, the average for the Danish population has increased from 2 to a little over 3 CFLs/home and part of the population using CFLs has raised from 50% to around

66%. Anyhow, it is a question how large an effort you should put into getting at 100% because some customer segments like very old people and students (moving often) are hard to reach. It may be more important to reward those already convinced, and when they are the majority a pat on the back and furnishing them with arguments may come to influence on non-owners.

#### **LONG TERM AVENUES FOR MORE USE OF ENERGY EFFICIENT LIGHTING**

Replacing incandescent lamps with screw-in CFLs without considering the entire luminaire often results in unanticipated losses in light output, severe degradation of the optical performance, and visual discomfort caused by glare. The CFL has an asymmetric intensity distribution which needs the right direction of the light.

The look-a-like CFL imitate the look of an incandescent lamp but is a defence approach with double ceiling, reducing the lumen output further and the lifetime is half that of the finger type.

An offence approach is needed, giving the CFL its own identity and features which differ from other lighting sources.

The two European Lighting Design Competitions [6] "Lights of the future for Energy-Efficient Dedicated Lighting Fixtures In The Residential Market" are supporting this approach through the key design objectives,

- Looking good decoratively
- Giving aesthetic lighting impact
- Exploiting new design, materials + technology
- Pricing and practicality of manufacture.

Light fittings that are eligible for submission under the competition rules can take only pin-based CFLs. Using only pin-based CFLs gives a dedicated fixture where the performance is better, it will avoid having a snap-back effect, where worn out CFLs are replaced with an ordinary incandescent light bulbs, and finally using pin-based CFLs it will only be necessary to replace the glass while the ballast can stay in the fixture due to a life of 40-50.000 hours.

While the competition is an important vehicle to encourage change towards more energy efficient light fittings, it is vitally important to promote the winning designs nationally and internationally to manufacturers, retailers, designers, the press, and the general public and thus get the winning designs in production and on the market.

It would be very good if exhibition stand, catalogue, website, and press material from the competition will be disseminated by organisations in most European countries.

Marketing of CFLs with built-in occupation or daylight sensor and thus automatic on/off control are also giving product identity. Dimming possibilities are needed too. The customers request lighting flexible in time and space in order to adapt to different modes.

#### **CONCLUSION**

A detailed analysis on the lighting pattern in 100 Danish homes has given the following results,

- The monthly average lighting consumption varies between 5% and 21% of the total respective monthly consumption. Although the lighting consumption is higher in winter, the above figures indicate that the lighting takes less than the standard value 20% of the yearly domestic consumption.
- There are 26.4 lamps in average per home, which is in very good line with national surveys, which have found 27 lamps per home.
- 6.1 lamps (24%) are energy efficient lamps (linear fluorescent lamps or CFLs).
- For the total number of lamps, 56% were incandescent lamps, 20% halogen lamps, 15% CFLs, and 9% linear fluorescent lamps.
- Looking at incandescent lamps, 40W is clearly the most popular lamp with 45%, followed by 25W with 29% and 60W with 18%. It is surprising that the number of 60W lamps is so low although some of the former 60W lamps have been replaced by CFLs.
- Regarding halogen lamps, 20W is the most popular with 57%, followed by 10W with 18% and 35W with 8%.
- Focusing on CFLs, 11W is the most popular with 33%, followed by 7W with 20%, 9W with 11%, and 15W with 10%. It is surprising that 7W is used so much. 49% of the lamps are below 11W, which is due to the poor information on the packaging on wattage comparison between incandescent lamps and CFLs leading to use of too small wattage and lumen output.
- Looking at linear fluorescent lamps, 18W is the most popular with 34%, followed by 36W with 21%, 15W with 14%, and 30W with 13%.

Analysing the use of lamps per type of room, the conclusions are,

- Incandescent lamps are used in all types of rooms.
- Halogen lamps are used in bathroom, entrance, kitchen, bedroom, and living room.
- Linear fluorescent tubes are primarily used in kitchens, followed by the washing/drying room and bathroom
- CFLs are primarily used in the living room follow by bedroom, entrance, kitchen, outdoors and office.

Incandescent lamps (56% of the number of lamps) takes 63% of the lighting consumption while halogen lamps (20% of the number of lamps) takes 16%. This indicates that in average the halogen lamps are used less than the incandescent lamps. For the efficient lighting sources, CFLs (15% of the number of lamps) takes 11% of the lighting consumption while linear fluorescent lamps also takes 11%. This tells that in average the linear fluorescent lamps have the highest number of burning hours and that the av-

erage burning hours for the efficient lamps are much higher.

The use of efficient lighting in the 100 homes is very different,

- In 12 of the homes more than 50% of the lighting consumption comes from energy efficient lighting (linear fluorescent lighting and CFLs).
- In 34 houses more than 25% of the lighting consumption comes from energy efficient lighting.
- 93% of the houses are owners of CFLs with an average of 4 CFLs per home. This is higher than the national figures: 2/3 of the Danish population own CFLs with an average of 3 CFLs per home.

On a short term, the potential for use of CFLs in Denmark is estimated to be 8 CFLs per home. The national CFL campaigns during the last two winters have been very successful. The price has fallen with the result that quality and right information on replacement of incandescent lamps with CFLs seems to be the most important issues.

The detailed load recordings at around 2000 lamps form the basis for calculation of consumption, hours of time and daily time of use and thus detailed calculation of the realistic potential for use of CFLs. It is the hope that funds will make this analysis possible in the future.

On a long term, it seems necessary to give CFL its own identity and features that differ from other lighting sources in order to reach a situation where CFLs is the major lighting source in the home. EU initiatives like "Light of the future" are supporting this development.

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