



BACHELOR THESIS

DEVELOPMENT OF A LIGHTING MODEL WITHIN A RESIDENTIAL ELECTRICITY SIMULATION TOOL

Bachelor in Electromechanical engineering

Student: **ALEJANDRO GARACH MARTÍNEZ**

Supervisor: **AKHILA JAMABAGI - TUM**

AUGUST 2015

ACKNOWLEDGEMENT

Firstly, I would like to express my sincere gratitude to Ms. Akhila Jambagi for the continuous support of my bachelor degree study and related research, for his patience, motivation, and immense knowledge. His guidance helped me in all the time of research of this thesis. I could not have imagined having a better advisor and mentor for my bachelor thesis.

I thank my peers from the exchange program in the year that I spend in Munich. All the discussions about the thesis were thankfully inspirational; they couldn't have been more supportive during my Erasmus experience. Also I thank my classmates and professors of ICAI, who along this four years have helped me develop not only as an engineer but also as a person.

Last but not the least, I would like to thank my family: my parents and brothers, specially my mother, for all the spiritual support throughout writing this thesis and my life in general.

ABSTRACT

This final degree project addresses the development of a Matlab model in order to simulate the profile demand of the lighting illumination of a standard household.

The immediate purpose of this type of model can be the development of new strategies to reduce the energy demand by an efficient use of it. The population increase and the concern with the climate change have lead to the issue of investigating the optimization of the energy demand, principally regarding the new energy efficient technology and its strategies.

This project takes into account the energy demand in a Household in Bayern by the Standard Load Profile (SLP), and the amount used in lighting, which is around 9%. The aim of the thesis is to perform a stochastic simulation model that can help to better understand the daily consumption in lighting in a Household for different resolution parameter.

The different parameters are:

1. The respective day of the year: The consumption will not be the same in Winter and Summer
2. Number of occupants in the Household. The SLP differs from 1-5+ number of persons at the dwelling within its respective consumption.

The firsts inputs are the time use survey (TUS) and the daylight hours, which define the probability of a better chance to use the lighting. From the TUS we can obtain the active occupancy (being at home and awoken) in a 15-min time resolution, whereas the daylight profile relates the necessity of artificial lights with the natural illumination between sunrise and sunset.

For the development of the main code of the model I have to focus on the event of turning on the lights. In every event load there are three principal characteristics that define every event:

- Start time: The specific time of the day when an occupant turns on the light.
- Amplitude: The wattage that illuminates the household in the event load.
- Duration: The difference between the start and end time of the event.

Finally, every event will be assigned in each household, depending on the capacity to support that amplitude and its respective active occupancy.

The final code will be implemented into the main research of the EESC, the residential electricity model, which includes similar models developed for different electricity consumptions such as cooking, television or refrigeration (among others).

RESUMEN DEL PROYECTO

Este proyecto de final de carrera ha abordado el desarrollo de un modelo en Matlab para simular el perfil de la demanda del consumo por parte de la electrificación en la iluminación de una vivienda estándar.

El objetivo que ha guiado la realización de este modelo ha sido la capacidad de desarrollar nuevas estrategias encaminadas a reducir la demanda de energía a través de un uso eficiente de la misma.

El aumento de la población y la concienciación de los gobiernos por el cambio climático, ha llevado a priorizar la investigación en este campo con el fin de obtener resultados eficientes en la optimización de la demanda de energía de las familias, teniendo siempre en cuenta las nuevas tecnologías y las estrategias más adecuadas que se han ido formulando en materia de eficiencia energética.

El proyecto se ha centrado en la demanda de energía eléctrica en una vivienda de Baviera, gracias a los datos recogidos por el *Standard Load Profile* de Baviera (SLP), y el correspondiente consumo utilizado en la iluminación, en torno al 9%.

El objetivo de la tesis ha sido realizar un modelo de simulación estocástica con el que se pueda comprender mejor el consumo diario de iluminación en un hogar, a partir de una serie de parámetros.

Los parámetros que se han considerado en el estudio han sido:

1. El periodo del tiempo (día del año): El consumo no va a ser el mismo en invierno que en verano.
2. Número de ocupantes en el hogar. La SLP se diferencia de 1-5 + número de personas en la vivienda dentro de su respectivo consumo.

Los primeros datos que se han manejado han sido: el *Time Use Survey* (TUS) y las horas de luz solar, que han definido la probabilidad con la que encendemos las luces a lo largo del día.

Con el TUS podemos obtener la ocupación activa (estar en casa y despierto) en una resolución de tiempo de 15 minutos de un día; mientras que el perfil de la luz solar se refiere a la necesidad de conseguir luz artificial al faltar la iluminación natural del sol, entre el amanecer y el atardecer.

Para el desarrollo del código principal del modelo se ha centrado en la generación de cada evento de carga que se produce cuando encendemos las luces.

Son tres las características principales que definen cada evento de carga:

- Hora de inicio: La hora específica del día en la que el ocupante de la vivienda enciende la luz.
- Amplitud: La potencia que ilumina la casa en la carga del evento.
- Duración: La diferencia entre el inicio y el final del evento.

Por último, cada evento de carga, en cada vivienda, será asignado en función de la capacidad que disponga para soportar la amplitud del evento y, en la medida, de que haya ocupación activa en ese intervalo de tiempo por parte de los miembros que la habitan.

El código final obtenido se integrará en el proyecto que está desarrollando el EESC, sobre el modelo de electricidad residencial, que incluye también otros modelos similares desarrollados para diferentes áreas de consumos de electricidad en una casa, como puede ser la cocina, la refrigeración o la televisión (entre otros).

TABLE OF CONTENT

1. Introduction	10
1.1. Europe Energy Framework	10
1.2. Why Energy Efficiency?	11
1.3. Residential Electricity Model	13
2. Lighting Model	16
2.1. Previous research	16
3. Construction of the model	19
3.1. TUS and Irradiance	20
3.2. Generation of events	21
<i>Start time</i>	23
<i>Duration</i>	23
<i>Amplitude</i>	25
3.3. Assigination to a Household	27
3.4. Results.....	28
4. Conclusions	33
4.1. LED technology	34
4.2. Further discussion.....	34
5. Appendix I: Useful Matlab functions	37
6. Appendix II: Code of the generation of event loads	39
7. References	44

LIST OF FIGURES

Figure 1: Europe’s primary energy production	11
Figure 2: Non-renewable vs Renewable energy.....	13
Figure 3: SLP consumption by HH type in 15 min resolution of a day	14
Figure 4: 4-Person household activity share.....	14
Figure 5: Diagram of the generation of events	19
Figure 6: Probability of active occupancy from TUS.....	20
Figure 7: Comparison of Irradiance level in two different days.....	21
Figure 8: Random Event Load after the simulation	22
Figure 9: Probability of starting time	23
Figure 10: Sample Lighting switching on events	24
Figure 11: Sample for weekdays and holidays.....	24
Figure 12: Average installed wattage per area in Denmark	26
Figure 13: Average installed wattage per area in England.....	26
Figure 14: Final sum of 100 HH timelines events.....	28
Figure 15: HH #60 timeline event load	29
Figure 16: HH #72 timeline event load	29
Figure 17: Simulation of 1st January in seconds.....	30
Figure 18: Sum of 100 HH for 1st of July.....	30

INTRODUCTION

1. INTRODUCTION

This Bachelor thesis has the aim to develop a model in Matlab, which realistically simulates the lighting power demand in a household. The project is included in one of the main research projects of the *EESC* group (Energy Efficient and Smart Cities) from the Munich School of Engineering in TUM (Technische Universität of München). The objective of this research is to develop a residential electricity model, which could help to improve the energy efficiency of the cities through the use of an accurate model demand of a residential electricity demand.

This constitutes an interesting topic because of the problems that we are facing with the worldwide energy demand, which leads to the issue of improving the energy efficiency in the daily electricity consume.

1.1. Europe Energy Framework

In the coming future plans of Europe, governments want to phase out nuclear power demand, and that requires a transformation of the energy landscape. Regarding this plan, the German Government has set out the strategy “*Energy Concept*”, which establishes renewable energies as a cornerstone of its future energy supply. This new challenge needs a reliable power supply through the integration of a large share of intermittent renewable energy sources. For instance, wind and solar renewable resources are limited not only by its requirement of land (1000MW of solar capacity requires 20 km²), but also by the difficulty of reliably meeting peak power demands. In order to achieve a reliable power supply, we need an intelligent and flexible electrical grid that allows for new ways of monitoring and managing power flows [1].

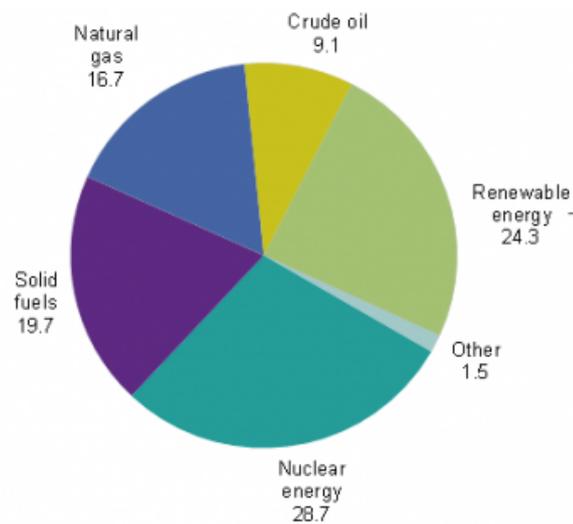


Figure 1: Europe's primary energy production

Along with supply-side measures, demand-side management is crucial in terms of improving the overall efficiency of our cities. By analyzing the existing urban energy systems, the EESC group seeks to address the techno-economic challenges facing the global green energy agenda. The research interests of the group are centered on integrated urban energy planning and their work includes energy efficiency of the built environment, coordination of heat and electricity in urban areas, and application of smart grids. The ultimate goal is to develop the evidence base for actions that can help to shape a sustainable and low carbon energy future.

1.2. Why Energy Efficiency?

We are facing a serious energy challenge; how to provide reliable and affordable supplies in the face of fast-growing demand and rising concerns for the environment.

Despite the investment in both renewable technology and sources, we need to burn millions of tons of fossil fuels in order to satisfy the demand of electricity. This fact derives to a main problem we should be more concerned, the contribution to global warming. If we made a more efficient use of the energy, we could significantly reduce the emissions, which affects the climate change. In addition, an efficient use of energy would help the resources last longer and save money.

Apart from to the environmental reasons, we could also point out more interesting views relating to efficient energy:

- **Economical:** Saving energy costs and creating new jobs from new energy efficiency projects such as building enhancements or infrastructure repairs.
- **Saving money:** buying energy-efficient appliances, making energy-efficient home improvements, and taking energy-efficient actions every day can save a considerable amount of money.
- **Quality of life:** Insulated buildings could maintain temperatures stable during Summer and Winter. Rarely changing the energy-efficient light bulbs at home is another result that we may not see, but improves our quality of life.

Renewables

Energy Efficiency and Renewables have been seen as competitors in terms of investment and attention, but the actual truth is that they are dependent of each other.

Europe has a goal of supplying our energy needs by 20% renewables by 2020, as it is explained in the introduction, the aim is to decrease the energy supply of nuclear power plants. Increased shares of renewables are currently under discussion for 2030 and onwards.

If we cut the energy demand, it would be much easier to reach the settled goal. Investing in energy efficiency would give us more time to improve the renewable technology and to avoid difficult decisions such as land use, food protection or landscape protection [2].

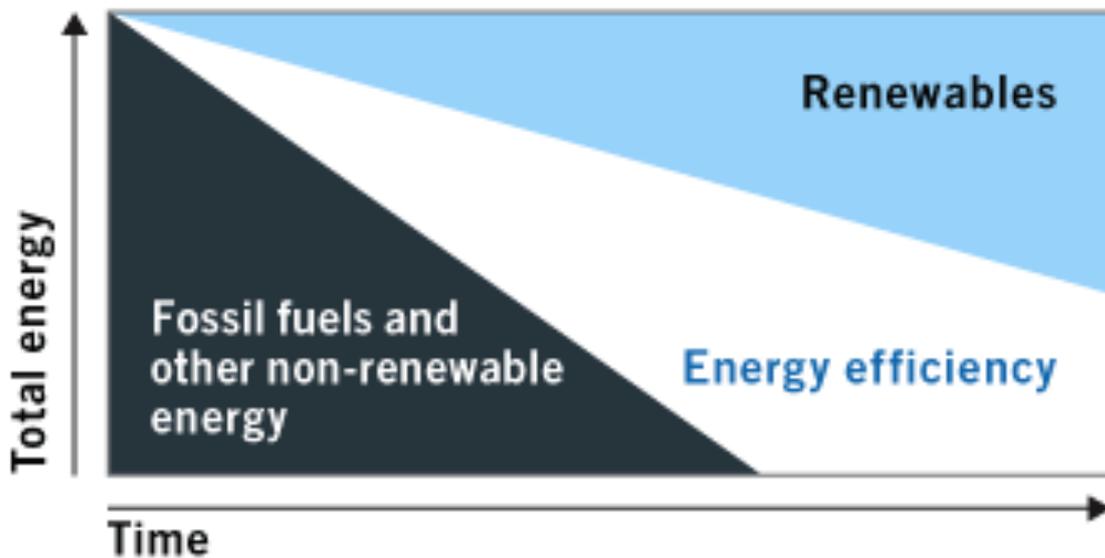


Figure 2: Non-renewable vs Renewable energy

1.3. Residential Electricity Model

An understanding of the existing energy use patterns remains of the outmost importance if we want to develop strategies to improve the energy efficiency of cities. To that effect, it is necessary to point out that the residential sector consumes 30% of the total energy demanded in Europe.

Since not all energy efficiency measures operate in the same space and time scales, a flexible time and space resolution becomes necessary for the model so as to correctly evaluate this measures. Thus, the model simulation goes as far as considering a single household with a time resolution of seconds. Moreover, in order to get a correct aggregate demand, the demand of the total population approaches the Standard Load Profile (SLP) from Bayern (Germany).

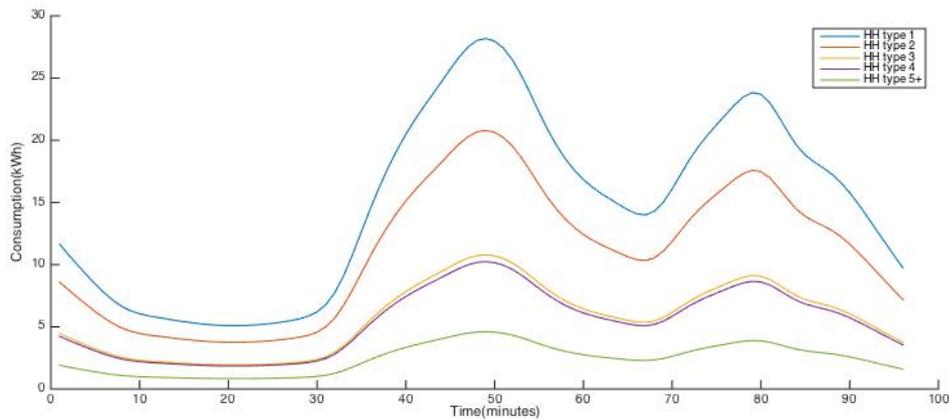


Figure 3: SLP consumption by HH type in 15 min resolution of a day

To accurately simulate household demand, individual appliance loads can be simulated following two existing approaches. Firstly, activity-based modeling, which uses Time Use Surveys to estimate probabilities of events [3]. Secondly, using aggregated data (SLP), and a breakdown of energy consumption per activity to generate events [4]. The novel approach of this work is to combine these two methods, using activity-based modeling for the more predictable loads, and then assigning the remainder using the standard load profile. This method will ensure that both the individual household loads are realistic, as well as the aggregated load for the total population.

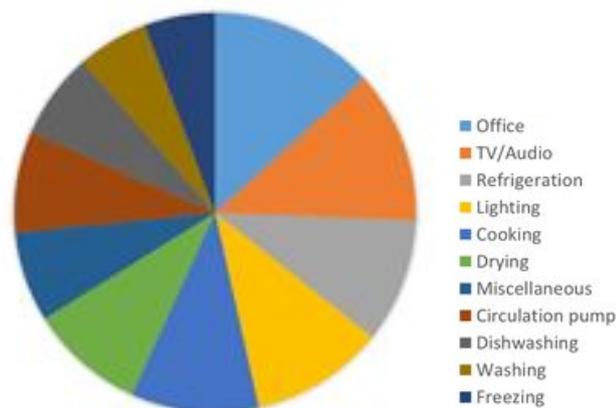


Figure 4: 4-Person household activity share

The model will be integrated with a spatial database, which contains information of existing buildings in the metropolitan area of Munich [5].

LIGHTING MODEL

2. LIGHTING MODEL

Lighting consumption is one of the basic end uses in all households and it also has a significant quote in the final electricity bill. That is one of the main reasons why we can see nowadays the optimization of the LED technology. But this thesis, rather than focusing in the specific technology that leads to the efficiency of the electrification of a household, has the aim of creating a high-resolution stochastic model for the lighting consumption profile.

The model takes into account the number of household residents based on the SLP from Bayern (Germany). We have the total amount of energy consumed in a HH differing between weekdays and weekends, from this point we can start our model taking into account the percentage of energy used in electricity in a standard HH.

2.1. Previous research

Seeking for further research and literature we can come across other studies, such as those referenced in the introduction of the residential electricity model, which constitute an important background to the construction of this model.

The model J. Widén is similar to the one that I have created, as it takes data from the TU data and it focuses in the irradiance level and an algorithm that generates probabilities based on the occupancy pattern.

Another interesting model is the one created by the Loughborough University [6]. Its model has inputs like natural lighting, lighting units and active occupancy, and they focus on creating a function for each dwelling.

Main difference of this model

The main objective is to create n event loads depending on the number of occupants that have the HH (We differ between 1, 2, 3, 4 and 5+) from the data of SLP.

The model of Widén is based in data from Sweden, while here I tend to collect data not only from Germany, but also from other countries with similar social behavior. In addition, the algorithm to obtain the probabilities is different from the one that I use in Matlab.

The Richardson's model highlights a function for each dwelling, in contrast with the approach I make in the generation of events. The aim of the model is to generate stochastic event loads in order to fulfill the total energy used by the number of occupants for a number of HH assigned before.

CONSTRUCTION OF THE MODEL

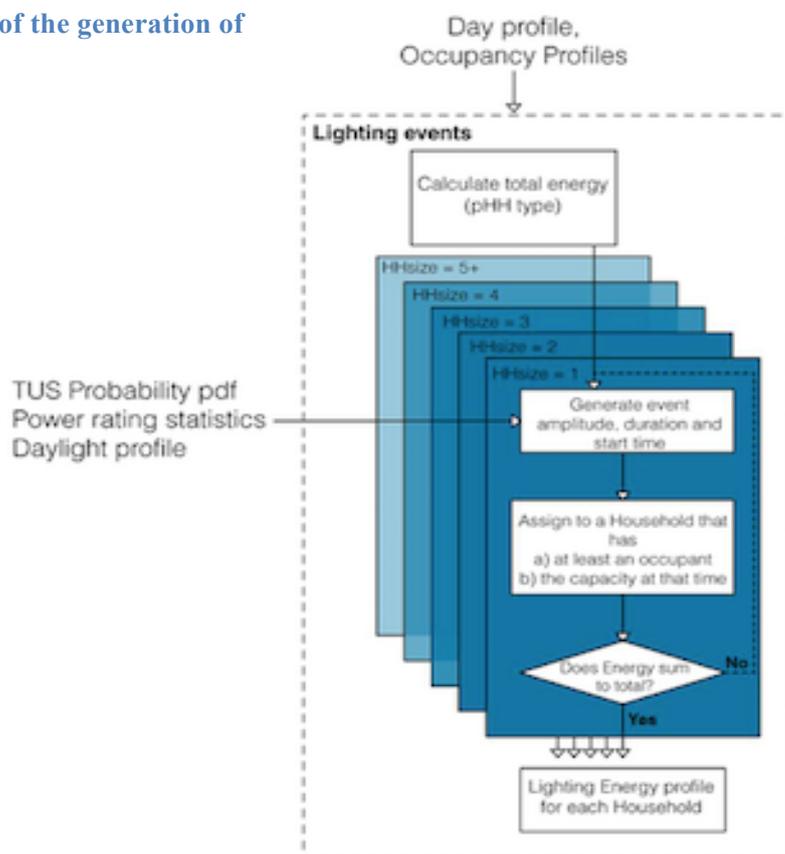
3. CONSTRUCTION OF THE MODEL

In order to implement the stochastic model, the first outline, which constitutes a bottom-up model, requires a number of input parameters to be entered as a first stage.

I implemented these parameters into probabilities in order to generate random events in every simulation. From previous studies we know that the standard percentage use in lighting of the total energy from the SLP is around 9%. Assuming this fact, we actually know the energy consumption for lighting, and then the second stage would be to think about the parameters that affect every event (turn-on/off lights).

The final simulation can be scaled either in seconds or in minutes, depending on the user issues. Luckily, to change the dimensions does not constitute a problem (only a factor of 1 min= 60 sec), so there is no need for searching double literature for the same parameter to discriminate literature because of the time scale

Figure 5: Diagram of the generation of events



3.1. TUS and Irradiance

From the TUS we focus in two parameters in order to generate a probability for the occupancy pattern. The first one is the active occupancy: 0 if there is nobody at home, and 1 if there is (someone) any person. In addition, if they are at home, they can be sleeping or not. From this data, I generate a normal distribution based on the day from the TUS, which I name in the code “*pmin*”.

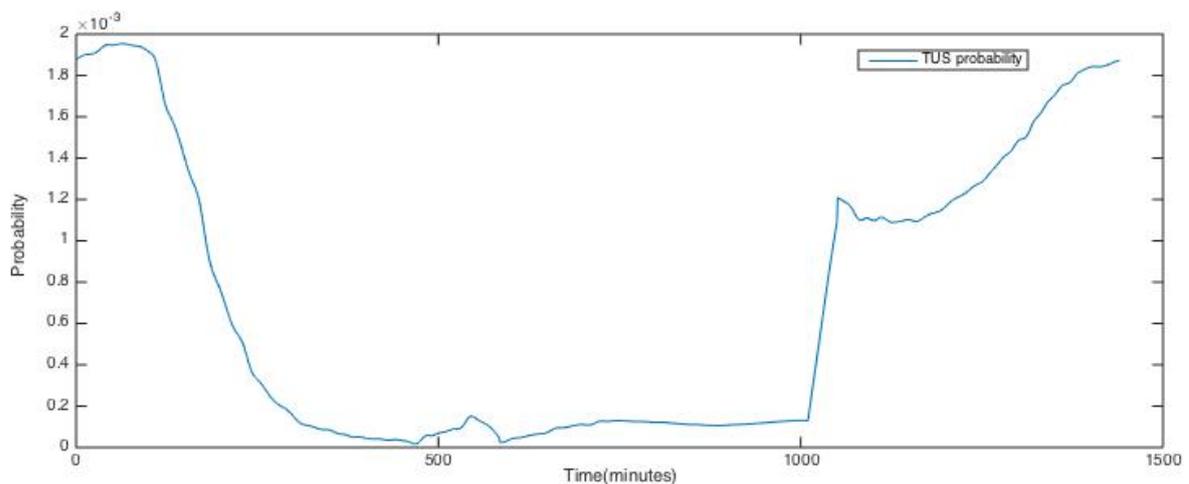


Figure 6: Probability of active occupancy from TUS

Let's consider how we usually have a normal chance to turn on the light, we have to take into account the solar irradiance at that specific day. We shouldn't forget that turning on the lights represents Watts consumption and, more importantly, this is reflected on the final electricity bill.

As we are focusing in the Bayern region, I looked into the sunset and sunrise hours for the whole 2015 year in Munich (Main city of Bavaria). Fortunately the data is available for any user [7], so the next step is to introduce it somehow in the model.

I transformed it in terms of probability like the data from the TUS, for that I have to make several assumptions with the irradiance level. The time defines when the sun rises and sets down, but nonetheless we should consider a time margin when there is not enough light and thus artificial light is needed. I set a delay of 40 minutes in both sunrise and sunset. Another assumption to be taken into consideration is to establish a minimum of irradiance level, as we can imagine they might be certain days where we need to turn on the lights, for example cloudy days. I set a minimum of irradiance greater than zero.

As these are inputs, any user could assume other numbers for the model with just a few modifications in the parameters, if considered otherwise.

This is an example of two random days of the year, and their respective irradiance level:

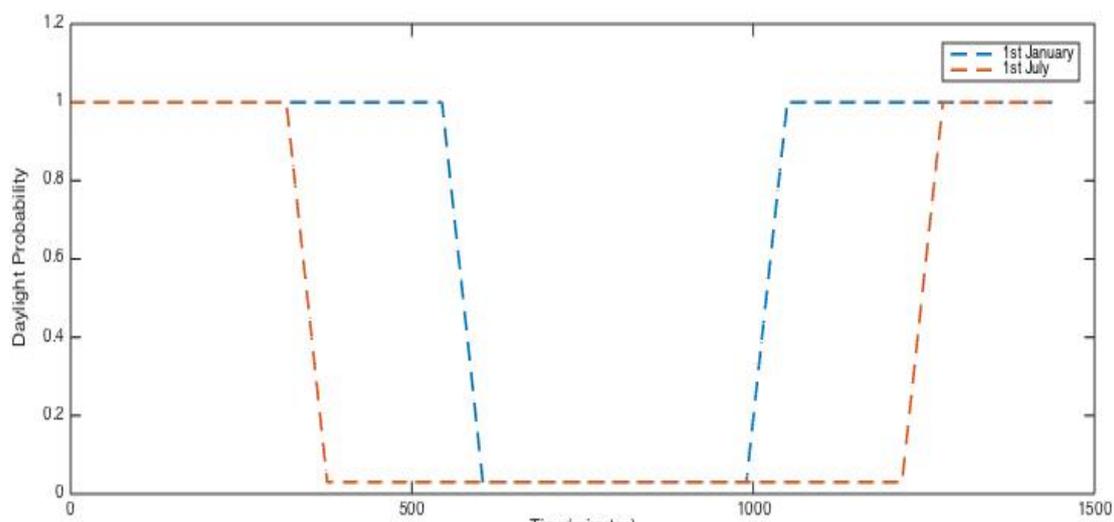


Figure 7: Comparison of Irradiance level in two different days

3.2. Generation of events

This is the main task of the thesis in order to model the code in Matlab. Even though this is a stochastic simulation, it is capital to support it with realistic data so as to get an optimal

solution output, (said data was obtained/extracted from the different literature...) that's why I had to research the different literature that could be applied in the event loads.

Even though this is a stochastic simulation, it is capital to support it with realistic data so as to get an optimal result.

Every event has three main characteristics: The start time of the event, represented by the decision of the person to turn on the lights at a certain time of the day. The amplitude for each event that remains constant until the event load finishes. And finally, the end time, which depends on the duration assigned.

For clarifying purposes, let's see an example of a random event after the final simulation:

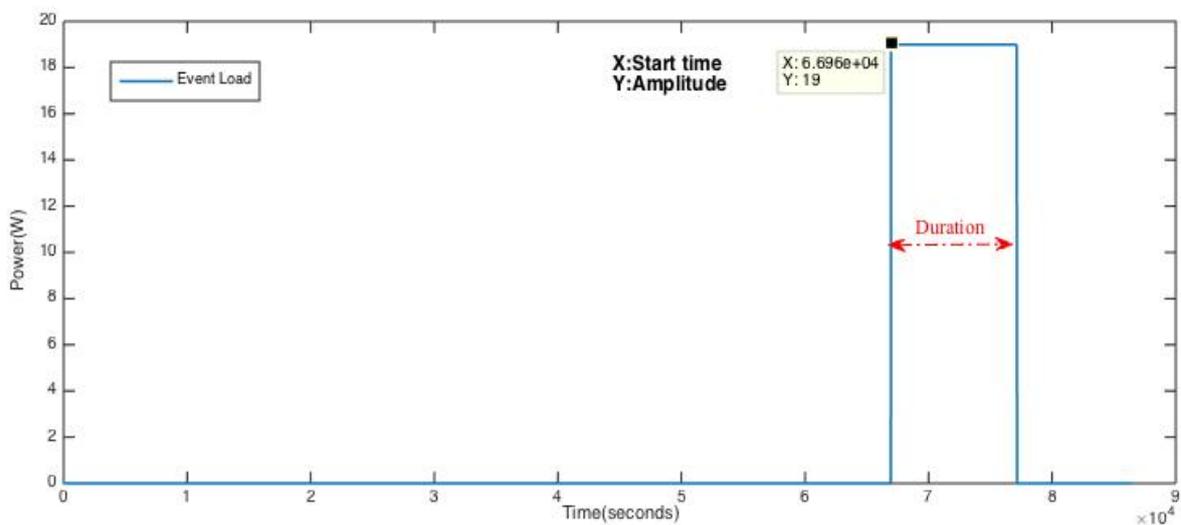


Figure 8: Random Event Load after the simulation

As we can see in Figure 4, the three main characteristics of the event are the ones mentioned before. **Start time:** $6.7e4$ seconds; **Amplitude:** 19 W; **Duration:** $1.02e4$ seconds.

Start time

The starting time of each event is based on the probability commented above. The starting point of every event is a random number based on the following probability:

$$p_{Start\ time} = p_{TUS} \times p_{Daylight}$$

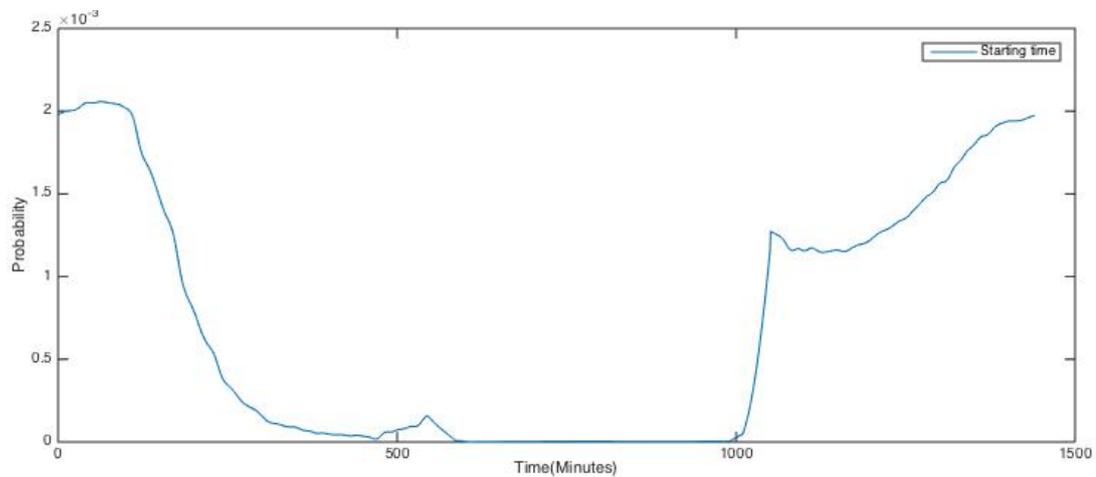


Figure 9: Probability of starting time

From the cumulative probability function, I randomly assign a certain time to every event with the function in Matlab: *histc()*. [In the *Appendix II* the whole simulation code is shown] Then the starting point depends on the specific day selected to run the simulation, as there are more chances to turn on the lights in Winter than in Summer because of the difference in the daylight hours restriction.

Duration

It wasn't easy to find data for the duration of the events, as it depends on many factors that are difficult to measure such as the human behavior. We can have a quick guess, for instance the events at night are longer than the ones in the morning, but it wasn't easy to find support for this fact.

Finally, I found an interesting survey of a 109 HH for the duration of the lighting events in a further study of a survey during holiday's period [8].

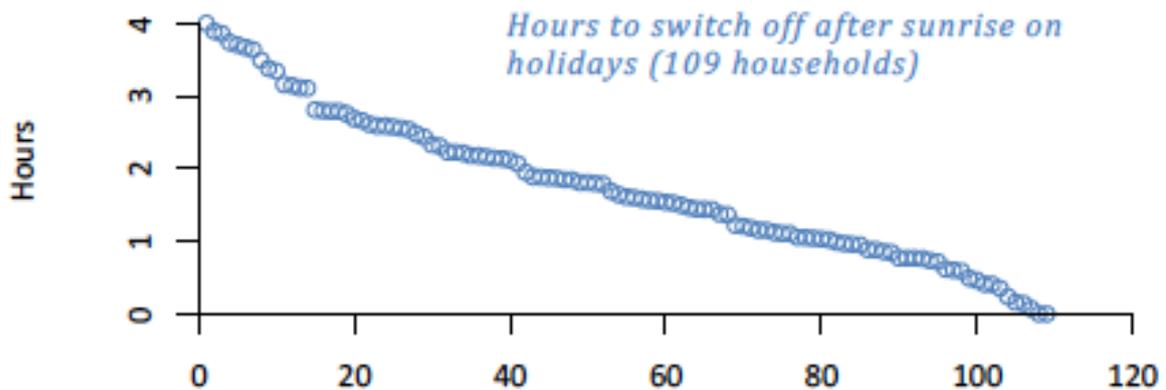


Figure 10: Sample Lighting switching on events

I assume the data for the model is correct, as I am not looking into the details whether the events are longer or shorter between weekdays/weekends or the period of the year, and the average of 2 hours in turning on/off the lights seems a reasonable event time. There is another example here, where we can observe that the mean tends to be around 2 hours time whether in work days or holidays:

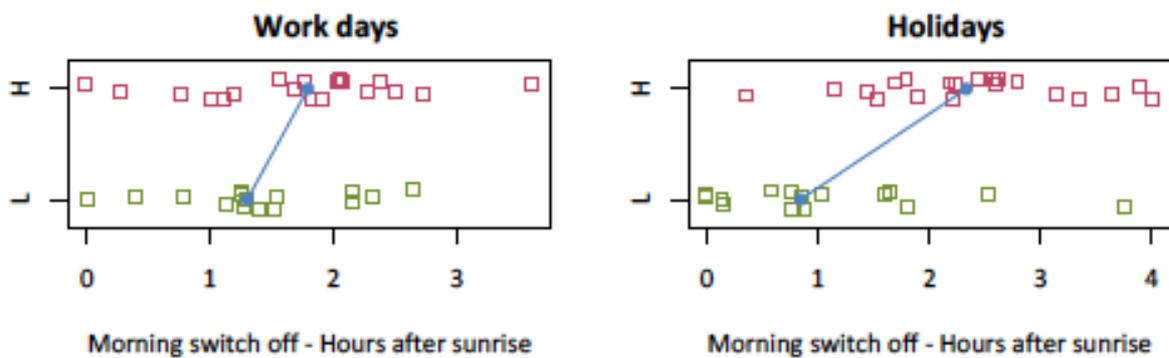


Figure 11: Sample for weekdays and holidays

Then, I finally created a normal distribution with a mean of 2 hours, and a standard deviation of 1 hour for the creation of the events, as they majority of events tend to be into this range after looking up for the data.

Amplitude

In order to assign certain amplitude for each event we have to take into account different parameters regarding the power consumption in lighting.

First of all, we should think about the number of lights that a HH can have, since each light should consume certain wattage. This brings up an interesting point of discussion: if we think carefully about the structure of a HH, which normally depends on the area of each HH, where it is more recommendable to use a LED bulb, a CFL or another type of bulb available in the lighting bulb market. This issue leads into an extensive documentation between the types of bulb used in the HH, because there are tangible differences in the wattage consumption, and regarding the model, the amplitude assign in each event.

That's why I rather focus in another parameter to obtain an amplitude probability, and I assume a standard type of bulb for the whole HH, as the main residential electricity model doesn't differ between bathroom, kitchen, living room, terrace or bedroom.

As the model is based on standard data, I researched the number of lights that is normalized within the different areas (m^2) that a HH could have. As a matter of fact, when the HH is bigger an increased number of lights are needed to cover the illuminated space; and less light bulbs are needed on a smaller HH.

After the research, I had to make several decisions because not only the data differs between the countries of the EU (European Union), but there also are many studies available, which could allow another approach for the amplitude assignment. For instance, we could establish a relation between squared meters and the wattage consumption, assuming that the number of lights and rate power is included within the area of the HH.

I decided to incorporate the approach of the power/area as it can be assumed that the number of lights and its power are supported by these statistics.

Unfortunately I couldn't find reports from Germany in the different European results, but I could find several sources of data from countries like Denmark [9] or England [10], but as it is shown in the following figures, they don't present the same results:

Denmark

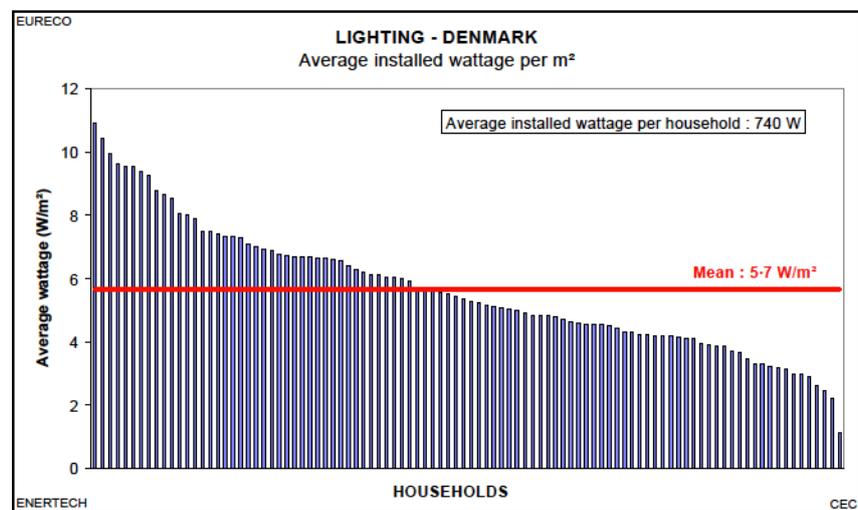


Figure 12: Average installed wattage per area in Denmark

England

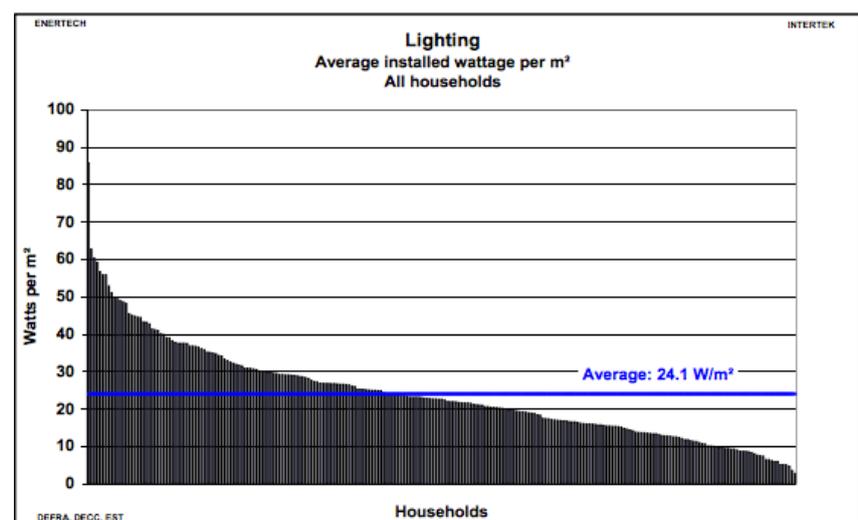


Figure 13: Average installed wattage per area in England

The most reasonable explanation of why the consumption in England is 4 times that of Denmark's lies in the different social habits in both countries. I looked for information to contrast the normal average consumption in other countries of the EU, such as Spain, whose average area and consumption are respectively 160 m² and 3750 W [11]. Taking into account this standard area we can notice that England has a similar power rate, and Denmark has a significantly low consumption.

Finally, after all these comparisons I decided to take the data from England, where they have similar behavior in their habits. Then, I created a probability density function from the data and I also assumed a range of areas for the HH, as standard as possible. The probability is made by: $\mu = 24.1 W/m^2$; $\sigma = 5W/m^2$; min= 5 W/m²; max= 85 W/m²;

3.3. Assignment to a Household

After each event has been created, it has to be assigned to one of the 100 HH (Each HH has its load profile from the SLP). The two main conditions that each HH requires are:

- 1) In the period of the event (from its starting time until its final time) there has to be at least one active (not sleeping) occupant at the HH. We know this from the TUS data.
- 2) After the first condition, only the HHs, which have the capacity to hold the event at that certain period of time without reaching its maximum power capacity, can be selected. Every event is stored in an available HH, so we should notice that the sum of events of a HH in a specific time can exceed its capacity to illuminate the house (we assume that in every event all the lights are turned on).

With these two conditions the main loop restarts another stochastic event, which is assigned to the different HHs until the total amount of energy is reached, which is the condition of exit of the main loop.

3.4. Results

The first inputs that the user should think about before the simulation are: the time resolution of the day (Seconds-86400 or Minutes-1440) and the day selected for the simulation (between 1 and 365 days). These two parameters will determine the day profile simulated and the scale of the results, whether in minutes or in seconds. When the simulation finishes, we obtain the different matrixes created during the simulation.

Here we can see an example of the simulation of the 1st of January in minutes for 1 occupant at the HH:

The sum of all the HH timelines event profiles is reflected in the following graph in order to understand how the consumption of a general number of HH behaves. In this thesis the number of HHs is set at 100, but in the final residential electricity model the number depends on the input from the user.

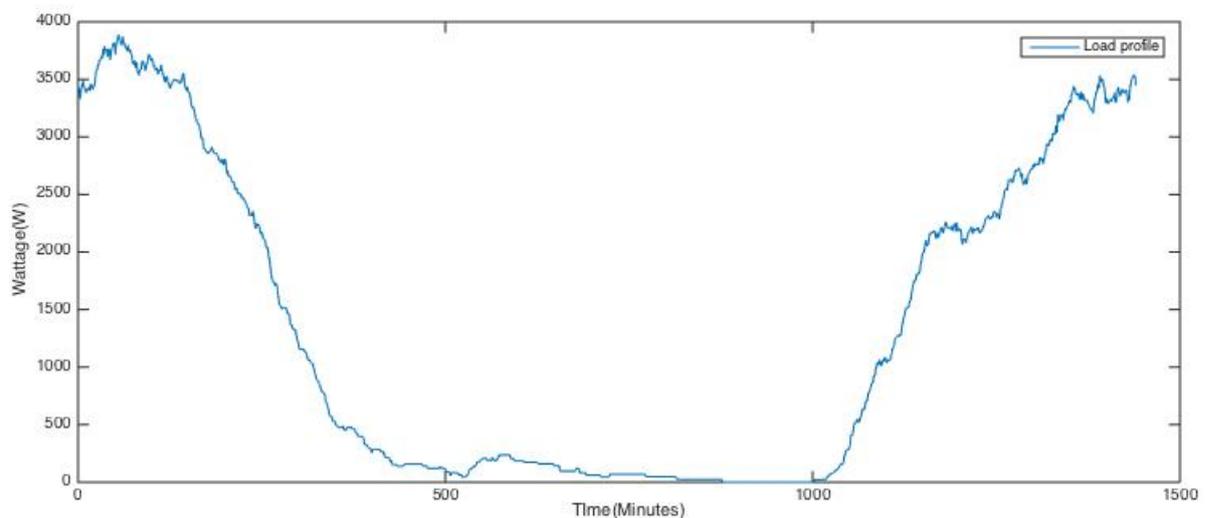


Figure 14: Final sum of 100 HH timelines events

If we look into the individual HH profiles, we can see how the events have been stacking up into each HH timeline:

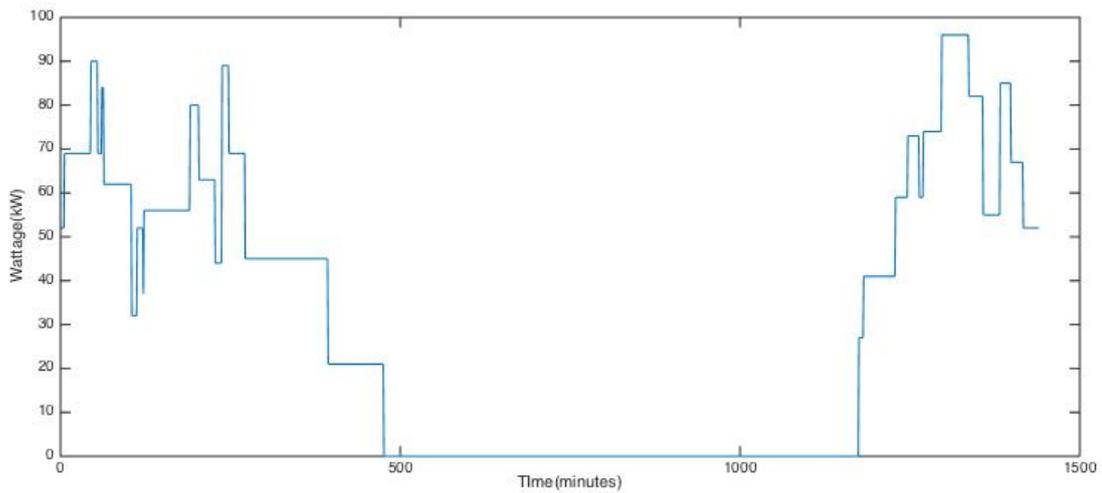


Figure 15: HH #60 timeline event load

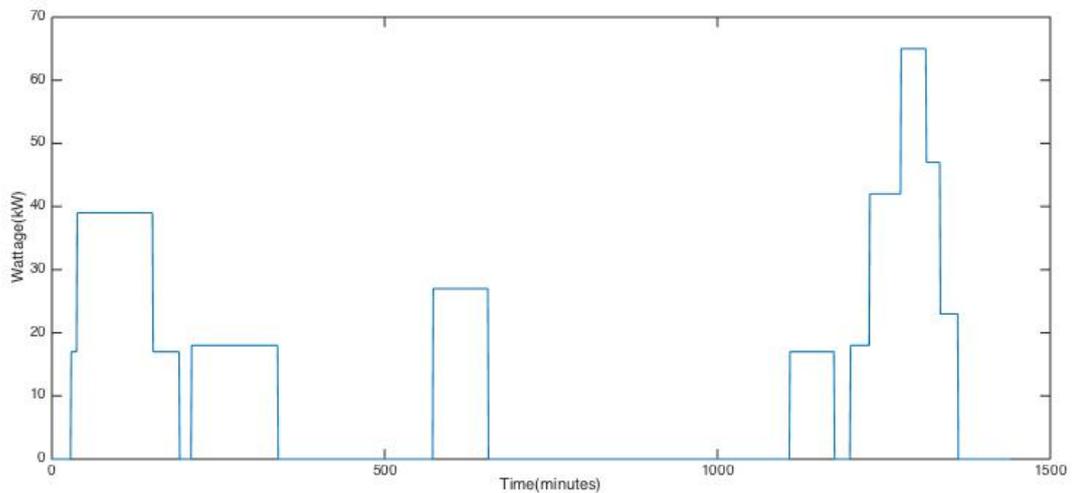


Figure 16: HH #72 timeline event load

Here is another stochastic simulation of the same day, but in this case the time resolution is set in seconds, and with 2 occupants:

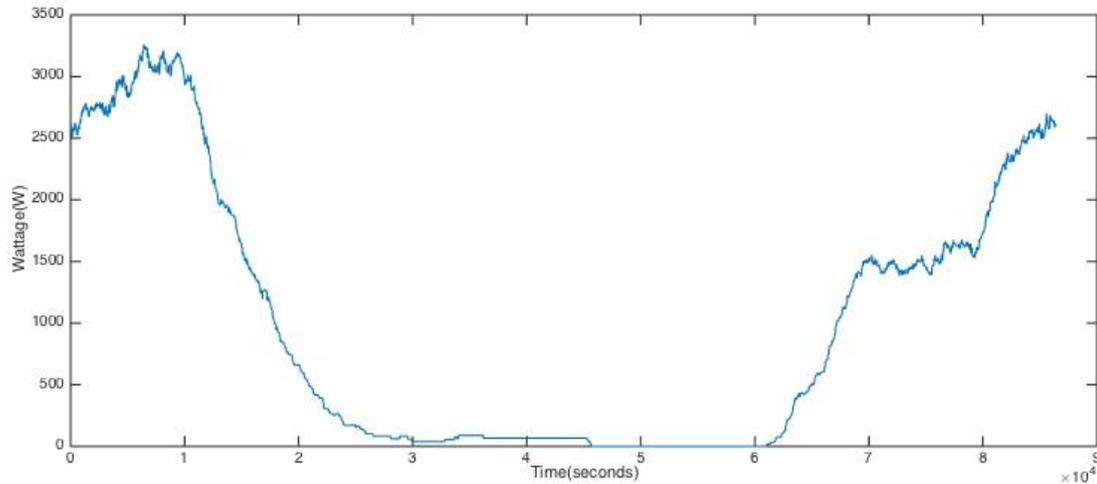


Figure 17: Simulation of 1st January in seconds

These two final simulations are based in the 1st of January, so I'll now make another stochastic simulation for a Summer day, when the daylight time is longer. Here is an example in minutes for the 1st of July for two occupants:

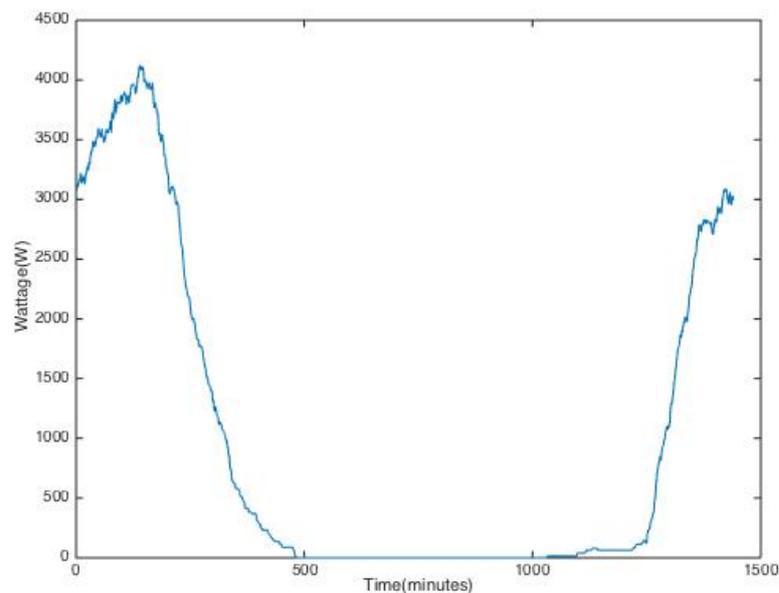


Figure 18: Sum of 100 HH for 1st of July

Comments

We can appreciate the behavior of the different simulations of the consumption during the day. First of all, we can see that the graph's shape is similar to the "*pmin*", as this probability holds the essential data in terms of obtaining an accurate result. That also gives us an idea of the behavior in turning on the lights at home. For instance, we can notice that from 17:00 until 01:00 we have the greatest consumption. This is when the occupants spend more time at home actively (not sleeping), so there is a higher chance to turn on the lights at this time.

We can also notice a little peak at lunchtime. I expected a greater consumption, as we normally tend to turn on the lights when we are preparing the meal. However, a reasonable explanation is the idea that during working hours, the HH is not occupied because the occupant is at work and cannot go back home for lunchtime. In case of more than two occupants, it is likely that there are children involved in the HH, however they should have the same timetable as their parents since the most reasonable assumption is that they are at school at lunchtime.

In addition, comparing the result with the Summer day, we can appreciate that the night peak occurs later. This is reasonable, as in Summer sunset is later than in Winter, so we tend to turn on the light at later hours of the night.

CONCLUSIONS

4. CONCLUSIONS

After the results obtained with Matlab, the model has presented the implementation, validation and simulation procedure for a stochastic model, which generates the consumption profiles of electricity use in lighting systems depending on the HH types. The model should have been calibrated for Bayern (Germany), but finally I've used data from different countries from the EU with similar social habits.

The final results are mainly demonstrated by the relationship between sunlight availability and active occupancy of dwellings with electricity consumption for lighting, which I previously labelled "*p_{min}*" and the daylight profile from Munich for 2015. The peak that stands out is in the afternoon, when there is the highest probability of active occupancy, and coincides with the sunset. I would have also expected before starting the thesis a higher peak for lunchtime, but the probability based in the TUS does not reveal a high activity at home at that time. For instance, if it were a model for Spain, this peak would probably be higher because of the long break during workdays, and the weather could also make a difference among other countries from the EU [12].

Subsequently, the model could be used to perform a study on the impact of LED technology's penetration into the residential sector or other energy saving policies. These changes would result in a conception of smart buildings. Then, a more efficient HH would implicate at an aggregate level a reduction of CO₂ for the region implemented without significant impacts on energy quality, since the power factor is only slightly affected and this reduction is compensated by lower active energy consumption.

Along with the developed model, the final goal of this work is to be integrated into the main Residential electricity model of the EESC that is being modeled. Once it is finished it will become a future prediction model, resulting in consumption predictions of the whole set of electrical appliances found in households, in order to obtain daily consumption profiles and annual trends.

This model, already being implemented and which will be discussed in future papers, will keep the same simulation philosophy as the current one, enabling us to use the predictions practically in order to propose and analyze the impact of new energy saving policies.

4.1. LED technology

The last Nobel Prize in Physics (2014) was shared between three Japanese Isamu Akasaki, Hiroshi Amano and Shuji Nakamura [13]. This honor is recognized for the invention of efficient blue light-emitting diodes, which has enabled bright and energy-saving white light sources. This technology has the advantage that it has a long range to be optimized and developed.

That's one of the main reasons I chose this topic to write my Bachelor Thesis; I'm proud that it could help to develop new strategies in terms of energy efficiency, such as the replacement of LED technology in the current lighting of the HH. That's why, I wanted to have a special mention to this type of lighting, which will probably be installed in all the smart buildings in the near future [14].

If we have a look into the history of lighting we could notice that the incandescent bulbs invented by Thomas Alva Edison has been the mainly source for lighting since its invention. It's time to invest in other technology more efficient such as the LEDs, or at least raise awareness into the society about the reduction of the energy demand of the particulars and its respective economical advantage by saving costs.

4.2. Further discussion

As it has been discussed in previous parts, the model can be improved in various ways. All of these options would however require more extensive amounts of input data or longer processing times. These are main the reasons why I decided to make some assumptions and simplifications in the first approach.

If these assumptions don't have a great impact in the results of the final model would lead into a sound balance between model complexity and output quality. With the present model structure sufficiently realistic load data can be generated and the improvements from further complexity would probably be marginal.

These simplifications depend on the model, for example some of the previous research comment that there isn't a significant difference weighting the power demand for different occupants, but we can't deny that as we get on deeper in the details, the model would be trivially more accurate [15].

These are some interesting points that could be implemented for a further research of this model:

- A larger TU data set, more specific sets of transition probabilities could be determined.
- As mentioned in the subsection *Amplitude*, there could be a more accurate result taking in account the type of light and the space where it is used. With this implementation, there could come up com interesting results, such as the relative use at the HH for different type of bulbs, for a further strategy commented: the impact of the LED technology in the HHs.

APPENDIX I: USEFUL MATLAB FUNCTIONS

5. APPENDIX I: USEFUL MATLAB FUNCTIONS

- ***Makedist(distname)***: Creates a probability distribution object for the distribution *distname*, using the default parameter values.
- ***pdf(pd,x)*** : Returns the probability density function of the probability distribution object, *pd*, evaluated at the values in *x*.
- ***cumsum(A)*** : Returns the cumulative sum of *A* starting at the beginning of the first array dimension in *A* whose size does not equal 1.
- ***histc(x,binranges)*** : Counts the number of values in *x* that are within each specified bin range. The input, *binranges*, determines the endpoints for each bin. The output, *bincounts*, contains the number of elements from *x* in each bin.
- ***zeros(n)***: Returns an *n*-by-*n* matrix of zeros.
- ***find(X)***: Returns a vector containing the linear indices of each nonzero element in array *X*.
- ***datasample(data,k)***: Returns *k* observations sampled uniformly at random, with replacement, from the data in *data*.
- ***rand(sz1,...,szN)***: Returns an *sz1*-by-...-by-*szN* array of random numbers where *sz1*,...,*szN* indicate the size of each dimension.
- ***isempty(A)*** : Returns logical 1 (true) if *A* is an empty array and logical 0 (false) otherwise.

APPENDIX II:

CODE OF THE GENERATION OF EVENT LOADS

6. APPENDIX II: CODE OF THE GENERATION OF EVENT LOADS

```
% Event Loop Lighting
% User input

request1='Please, select 1 for seconds, or 60 for minutes:\n';
res= input(request1);

% res = 1; % Seconds
% res = 60; % Minutes

request2='Please, select a day: ';

day = input(request2);

if day<=0 || day>365
    fprintf('You have typed a wrong day\n');
    request='Please, select a new day: ';
    day = input(request);
end

load('Set_up_Lighting.mat')
total = 0.25*0.09*sum(day_profile,1);
i = 1;
Energy = 0;

%%Duration Probability:
Duration_pd=makedist('Normal','mu',2*60,'sigma',1*60);
Duration_prob=pdf(Duration_pd,[1:1:240]);
Duration_prob=Duration_prob/sum(Duration_prob);

%% Initialise Timeline vectors / database
HH_Timeline_lighting = zeros(100, 86400/res);
```

```
%% Day input:
Start_timeprob=pmin'.*Prob_daylight(day,:);
Starting_time=Start_timeprob/sum(Start_timeprob);

%%
while Energy < total(1)
    % Your task
    %% Start time

    cumprob = cumsum(Starting_time);
    Randnum = rand(1,1);
    [~, start_time(i)] = histc(Randnum, cumprob);
    a(i) = start_time(i)*60/res;

    %% Amplitude
    RandAmp=rand(1,1);
    Amp=0;
    [~,Amp]=histc(RandAmp,England_cumprob);
    Amplitude(i)= Amp;

    %% Duration
    %Prob = 1/(60*4)*ones(4*60, 1);
    RandDur=rand(1,1);
    cumprob_Duration=cumsum(Duration_prob);
    [~, duration(i)] = histc(RandDur, cumprob_Duration);
    duration(i)=duration(i)*60/res;

    %% Eventload = First way:
    if a(i)+duration(i)>86400/res
        Night=86400/res-a(i);
        Morning=duration(i)-Night;
        for n= 1:86400/res
            if n<=Morning
                Eventload(i,n)=Amplitude(i);
            elseif n>Morning && n<Morning+86400/res-
duration(i)
                Eventload(i,n)=0;
            else
                Eventload(i,n)=Amplitude(i);
            end
        end
    end
end
```

```
        end
    else
        for n = 1:86400/res
            if n >= a(i) && n <= a(i) + duration(i);
                Eventload(i,n) = Amplitude(i);
            else
                Eventload(i,n)=0;
            end
        end
    end
end

%% Eventload= Second way:
%   if a(i) + duration(i) < (86400/res)
%       Eventload(i,:) = [zeros(a(i), 1);
%       Amplitude(i)*ones(duration(i),1);...
%       zeros((86400/res) - a(i) - duration(i),1)];
%   else
%       dur1 = a(i) + duration(i) - (86400/res);
%       Eventload(i,:) = [Amplitude(i)*ones(dur1,1);
%       zeros((a(i) - dur1),1);...
%       Amplitude(i)*ones((duration(i) - dur1),1)];
%   end

Event_energy= sum(Eventload(i,:))/(1000*(3600/res));
Energy = Energy + Event_energy;

%% Assign to a Household

t = find(Eventload(i,:));

% Condition 1: THE household has an occupant at the time
if res ==60
    t10 = find(downsample(Eventload(i,:), (10)));
    CheckOcc = HH_Occupancy(:, t10);
    occupied = find(sum(CheckOcc,2)==size(CheckOcc,2));

elseif res==1
    t60= find(downsample(Eventload(i,:), (600)));

    CheckOcc = HH_Occupancy(:, t60);
    occupied = find(sum(CheckOcc,2)==size(CheckOcc,2));
```

```
end

    %% Condition 2: There is the capacity to turn on the light
    at the time
    Size_occupied=length(occupied);
    Max_Power = table2array(HHdb(:,3));
    t=1;
    available=[];

    for j=1:1:Size_occupied
        a=occupied(j);

Current_power=HH_Timeline_lighting(a,:)+Eventload(i,:);
        Max=max(Current_power);
        if Max <= Max_Power(a)
            available(t) = a;
            t=t+1;
        end
    end

    %% Condition where there are no HH, so we erase the
    current Eventload
    if isempty(available)
        Energy = Energy - Event_energy;
        i=i-1;
    else
        %% Assign to occupied household
        HHevent = datasample(available,1);
        HH_Timeline_lighting(HHevent, :) =
HH_Timeline_lighting(HHevent, :) + Eventload(i, :);

    end

    i = i+1;

end
plot(sum(HH_Timeline_lighting, 1))
```

REFERENCES

7. REFERENCES

- [1] “Eurostat, Statistics Explained” [http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Production_of_primary_energy,_EU-28,_2013_\(%25_of_total,_based_on_tonnes_of_oil_equivalent\)_YB15.png](http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Production_of_primary_energy,_EU-28,_2013_(%25_of_total,_based_on_tonnes_of_oil_equivalent)_YB15.png)
- [2] “European council for an energy efficient economy”. http://www.ecee.org/about-ecee/why_energy_efficiency
- [3] J. Widén, E. Wäckelgård, A High-Resolution Stochastic Model of Domestic Activity Patterns and Electricity Demand, *Applied Energy* 87 (2010)”
- [4] “C. Molitor, K. Togawa, S. Bolte, A. Monti, Load Models for Home Energy System and Micro Grid Simulations, 2012 3rd IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe), Berlin.”
- [5] “A. Jambagi, M. Kramer and V. Cheng. (2014), Modelling residential electricity demand at high temporal and spatial resolution, MSE colloquium 2014: Energy in Motion, 3rd July 2014, Munich.”
- [6] “RICHARDSON, I. ... et al, 2009. Domestic lighting: a highresolution energy demand model. *Energy and Buildings*, 41 (7), pp. 781-789” Elsevier. <https://dspace.lboro.ac.uk/dspace-jspui/handle/2134/4759>
- [7] “Sunrise, sunset and daylength. Munich, Germany. 2015” <http://www.timeanddate.com/sun/germany/munich>
- [8] “Further Analysis of the Household Electricity Survey: Lighting Study (Final Report)” Nicola Terry, Jason Palmer, Daniel Godoy, Steven Firth, Tom Kane, Amy Tillson. 21 May-2013. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/326085/Lighting_Report.pdf
- [9] “Commission of the European Communities. Demand-Side Management. End-use metering campaign in 400 households of the European Community. Assessment of the Potential Electricity Savings. Project EURECO”. January 2003 http://www.eerg.it/resource/pages/it/Progetti__MICENE/finalreporteureco2002.pdf

- [10] “Household Electricity Survey A study of domestic electrical product usage 327-340. Intertek Testing & Certification Ltd.” Jean-Paul Zimmermann, Matt Evans, Jonathan Griggs, Nicola King, Les Harding, Penelope Roberts, Chris Evans. May 2012.
- [11] “Ministerio de Industria , Energia y Consumo. España. Legislación seguridad industrial.REBT. Guía Técnica de aplicación al Reglamento Electrotécnico de Baja Tensión. Previsión de cargas para suministros de baja tensión.” Septiembre 2003. http://www.f2i2.net/Documentos/LSI/rbt/guias/guia_bt_10_sep03R1.pdf
- [12] “Stochastic model for lighting’s electricity consumption in the residential sector. Impact of energy saving actions. Energy and Buildings 89 (2015) 245–259.” E.J. Palacios-Garcia, A. Chen, I. Santiago*, F.J. Bellido-Outeiriño, J.M. Flores-Arias, A. Moreno-Munoz. 2014 Elsevier B.V. “Residential lighting load profile modeling. Energy and Buildings 90 (2015) 29–40”. O. Popoola, J. Munda, A. Mpanda. 2015 Elsevier B.V.
- [13] “The Nobel Prize in Physics 2015”. *Nobelprize.org*. Nobel Media AB 2014. Web. 4 Aug 2015. http://www.nobelprize.org/nobel_prizes/physics/laureates/2015/
- [14] “The Story Behind Shuji Nakamura's Invention of Blue LEDs.” *Angela Yang. Judy Lin. October.14, 2014*. http://www.ledinside.com/news/2014/10/the_story_behind_shuji_nakamuras_invention_of_blue_leds
- [15] “Stochastic model for lighting’s electricity consumption in the residential sector. Impact of energy saving actions. Energy and Buildings 89 (2015) 245–259.” E.J. Palacios-Garcia, A. Chen, I. Santiago*, F.J. Bellido-Outeiriño, J.M. Flores-Arias, A. Moreno-Munoz. 2014 Elsevier B.V.

AUTORIZACIÓN PARA LA DIGITALIZACIÓN, DEPÓSITO Y DIVULGACIÓN EN ACCESO ABIERTO (RESTRINGIDO) DE DOCUMENTACIÓN

1º. Declaración de la autoría y acreditación de la misma.

El autor D. Alejandro Garach Martinez , como alumno de la UNIVERSIDAD PONTIFICIA COMILLAS (COMILLAS), DECLARA

que es el titular de los derechos de propiedad intelectual, objeto de la presente cesión, en relación con la obra trabajo final de grado, que ésta es una obra original, y que ostenta la condición de autor en el sentido que otorga la Ley de Propiedad Intelectual como titular único o cotitular de la obra.

En caso de ser cotitular, el autor (firmante) declara asimismo que cuenta con el consentimiento de los restantes titulares para hacer la presente cesión. En caso de previa cesión a terceros de derechos de explotación de la obra, el autor declara que tiene la oportuna autorización de dichos titulares de derechos a los fines de esta cesión o bien que retiene la facultad de ceder estos derechos en la forma prevista en la presente cesión y así lo acredita.

2º. Objeto y fines de la cesión.

Con el fin de dar la máxima difusión a la obra citada a través del Repositorio institucional de la Universidad y hacer posible su utilización de forma libre y gratuita (con las limitaciones que más adelante se detallan) por todos los usuarios del repositorio y del portal e-ciencia, el autor CEDE a la Universidad Pontificia Comillas de forma gratuita y no exclusiva, por el máximo plazo legal y con ámbito universal, los derechos de digitalización, de archivo, de reproducción, de distribución, de comunicación pública, incluido el derecho de puesta a disposición electrónica, tal y como se describen en la Ley de Propiedad Intelectual. El derecho de transformación se cede a los únicos efectos de lo dispuesto en la letra (a) del apartado siguiente.

3º. Condiciones de la cesión.

Sin perjuicio de la titularidad de la obra, que sigue correspondiendo a su autor, la cesión de derechos contemplada en esta licencia, el repositorio institucional podrá:

(a) Transformarla para adaptarla a cualquier tecnología susceptible de incorporarla a internet; realizar adaptaciones para hacer posible la utilización de la obra en formatos electrónicos, así como incorporar metadatos para realizar el registro de la obra e incorporar “marcas de agua” o cualquier otro sistema de seguridad o de protección.

(b) Reproducirla en un soporte digital para su incorporación a una base de datos electrónica, incluyendo el derecho de reproducir y almacenar la obra en servidores, a los efectos de garantizar su seguridad, conservación y preservar el formato. .

(c) Comunicarla y ponerla a disposición del público a través de un archivo abierto institucional, accesible de modo libre y gratuito a través de internet.

(d) Distribuir copias electrónicas de la obra a los usuarios en un soporte digital.

4º. Derechos del autor.

El autor, en tanto que titular de una obra que cede con carácter no exclusivo a la Universidad por medio de su registro en el Repositorio Institucional tiene derecho a:

- a) A que la Universidad identifique claramente su nombre como el autor o propietario de los derechos del documento.
- b) Comunicar y dar publicidad a la obra en la versión que ceda y en otras posteriores a través de cualquier medio.
- c) Solicitar la retirada de la obra del repositorio por causa justificada. A tal fin deberá ponerse en contacto con el vicerrector/a de investigación (curiarte@rec.upcomillas.es).
- d) Autorizar expresamente a COMILLAS para, en su caso, realizar los trámites necesarios para la obtención del ISBN.
- d) Recibir notificación fehaciente de cualquier reclamación que puedan formular terceras personas en relación con la obra y, en particular, de reclamaciones relativas a los derechos de propiedad intelectual sobre ella.

5º. Deberes del autor.

El autor se compromete a:

- a) Garantizar que el compromiso que adquiere mediante el presente escrito no infringe ningún derecho de terceros, ya sean de propiedad industrial, intelectual o cualquier otro.
- b) Garantizar que el contenido de las obras no atenta contra los derechos al honor, a la intimidad y a la imagen de terceros.
- c) Asumir toda reclamación o responsabilidad, incluyendo las indemnizaciones por daños, que pudieran ejercitarse contra la Universidad por terceros que vieran infringidos sus derechos e intereses a causa de la cesión.
- d) Asumir la responsabilidad en el caso de que las instituciones fueran condenadas por infracción de derechos derivada de las obras objeto de la cesión.

6º. Fines y funcionamiento del Repositorio Institucional.

La obra se pondrá a disposición de los usuarios para que hagan de ella un uso justo y respetuoso con los derechos del autor, según lo permitido por la legislación aplicable, y con fines de estudio, investigación, o cualquier otro fin lícito. Con dicha finalidad, la Universidad asume los siguientes deberes y se reserva las siguientes facultades:

a) Deberes del repositorio Institucional:

- La Universidad informará a los usuarios del archivo sobre los usos permitidos, y no garantiza ni asume responsabilidad alguna por otras formas en que los usuarios hagan un uso posterior de las

obras no conforme con la legislación vigente. El uso posterior, más allá de la copia privada, requerirá que se cite la fuente y se reconozca la autoría, que no se obtenga beneficio comercial, y que no se realicen obras derivadas.

- La Universidad no revisará el contenido de las obras, que en todo caso permanecerá bajo la responsabilidad exclusiva del autor y no estará obligada a ejercitar acciones legales en nombre del autor en el supuesto de infracciones a derechos de propiedad intelectual derivados del depósito y archivo de las obras. El autor renuncia a cualquier reclamación frente a la Universidad por las formas no ajustadas a la legislación vigente en que los usuarios hagan uso de las obras.

- La Universidad adoptará las medidas necesarias para la preservación de la obra en un futuro.

b) Derechos que se reserva el Repositorio institucional respecto de las obras en él registradas:

- retirar la obra, previa notificación al autor, en supuestos suficientemente justificados, o en caso de reclamaciones de terceros.