

# Energy Data Analysis with R

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# Chapter 1

## Preface

This book gives you an overview of the statistical software R and its ability to analyze and visualize time series in the context of building energy and comfort.

It is aimed at R beginners as well as experienced R users and is strongly inspired by the R Graphics Cookbook and Engineering Data Analysis in R. The aim of this book is to provide additional specific recipes for energy and comfort related tasks and to make your entry into R smooth and easy.

### 1.1 Content

The book is structured in the following main parts:

- R Basics
- Data Visualizations

The part “R Basics” covers general data analysis tasks like data loading, wrangling and aggregation. Mostly this part deals with number juggling and table viewing. An “R-beginner” receives as well information about the installation of the program environment and gets a quick and practical introduction.

“Numerical quantities focus on expected values, graphical summaries on unexpected values.” - John W. Tukey

Such so called “graphical summaries” are covered in the part “Data Visualizations” which brings the calculated numbers to life. Visualizations are good to identify patterns, changes over time, unusual readings, and relationships between variables. The presented code makes the creation of common and useful

plots for energy and comfort data fast and easy. The recipes in this part will show you how to complete certain specific tasks. Examples are shown so that you can understand the basic principle and reproduce the analysis or visualization with your own data. Simply copy the code into your R-script, replace the sample data files with your own and execute the code.

## 1.2 Why R and RStudio?

In a study commissioned by the Swiss Federal Office of Energy, experts from the field were asked how and where they perform energy analyses and create visualizations. The result was that many people today either need Excel or use a building monitoring software to execute analysis and create visualizations.

Excel users are pushing the program to its limits with the ever-increasing data sets. Also the interactive ability of the graphics there is limited. The change to an environment like “R” seems to be difficult for many. In the market there are numerous books which make the change to “R” for other disciplines easier. However, experts from the energy and building services engineering industry lack a corresponding work. The present book is intended to close this gap.

The freely available programming language “R” and its graphical user interface “RStudio” offer many more possibilities for data analysis and data visualization.

## 1.3 Further Reading

A really good source is [R for Data Science](<http://r4ds.had.co.nz>){target=”\_blank”} by Garrett Grolemund and Hadley Wickham. The entire book is freely available online through the same format of this book.

There are a number of recommendable free online books available, including:

- R Graphics Cookbook
- Introduction to Data Science - Data Analysis and Prediction Algorithms with R
- Hands-On Programming with R
- Engineering Data Analysis in R
- Forecasting: Principles and Practice
- AFIT Data Science Lab R Programming Guide

## 1.4 Acknowledgements

The author would like to express his sincere thank to the Swiss Federal Office of Energy, as the launch of this book was part of a project of the research program “Buildings and Cities 2018”.

This book was developed using Yihui Xie’s bookdown framework. The book is built using code that combines R code, data, and text to create a book for which R code and examples can be re-executed every time the book is re-built.

The online book is hosted using GitHub’s free GitHub Pages. All material for this book is available and can be explored at the book’s GitHub repository.



# Chapter 2

## Getting started

Before we can start with the analysis described in the later chapters, we have to install “R”. Therefore the first two parts of this chapter get you up and running with downloading and installing the relevant software and packages.

This may seem laborious, but it is necessary and easier than it appears at first glance.

If you already have “R” and “R Studio” installed, please take a look at the <https://github.com/hslu-ige-laes/redutils> package on github, which is frequently used throughout this book. Chapter 2.2 shows you how to install it.

Finally “R-beginners” find in 2.3 an easy code example which creates a simple time series plot.

### 2.1 Install R and R Studio

Before we can start the first analysis, we have to install “R” and “RStudio”.

- “R” is a programming language used for statistical computing while “RStudio” provides a graphical user interface
- “R” may be used without “RStudio”, but “RStudio” may not be used without “R”
- Both, “R” and “RStudio” are free of charge and there are no licence fees
- When you later make an analysis and visualizations, you only work in the graphical user interface “RStudio”

### 2.1.1 Download and Install R

Windows

1. Open <https://cran.r-project.org/bin/windows/base/> and press the link “Download R...”
2. Run the downloaded installer file and follow the installation wizard

The wizard will install “R” into your **Program Files** folders and adds a shortcut in your Start menu. Note that you will need to have all necessary administration rights to install new software on your machine.

Mac OSX 1. Open <https://cran.r-project.org/bin/macosx/> and download the latest \*.pkg file 1. Run the downloaded installer file and follow the installation wizard

The installer allows you to customize your installation. However the default values will be suitable for most users.

Liux “R” is part of many Linux distributions, therefore you should check with your Linux package management system if it’s already installed.

The CRAN website provides files to build “R” from source on Debian, Redhat, SUSE, and Ubuntu systems under the link “Download R for Linux”

- Open <https://cran.r-project.org/bin/linux/> and then follow the directory trail to the version of Linux you wish to install R on top of

The exact installation procedure will vary depending on your Linux operating system. CRAN supports the process by grouping each set of source files with documentation or README files that explain how to install on your system.

### 2.1.2 Download and Install RStudio

1. Open <https://rstudio.com/products/rstudio/download/> and download “RStudio Desktop Open Source”
2. Follow the on-screen instructions
3. Once you have installed “R Studio”, you can run it like any other application by clicking the program icon

## 2.2 Install required packages

Appendix A gives you an introduction to what a package is and how to install it. Below are the packages used in this book and it is recommended to install them.

- Open “RStudio” just as you would any program, by clicking on its icon
- Copy the following code and paste it into your console (on the bottom left, right of the symbol >):

```
install.packages("devtools", "tidyverse", "plotly", "lubridate", "r2d3")
install_github("hslu-ige-laes/redutils")
```

- Press **Enter** or **Return**

The installation of the packages is now in progress and this may take a while, please be patient. In the meantime you can read in appendix A what packages are in general and how they can be installed and later loaded into scripts.

## 2.3 Create your first R Script

Finally, you have installed “R” and “RStudio” with some packages on your computer. Good, hopefully everything worked fine up to now.

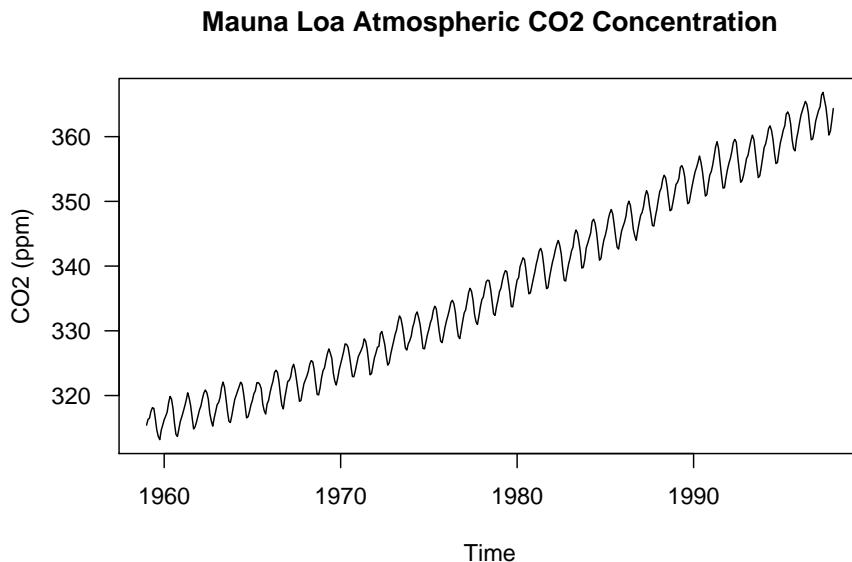
Let’s create the first script with a visualization:

- Open “RStudio” just as you would any program, by clicking on its icon
- Go to the menu on the top left and click to **File / New File / R Script**
- Copy the following code and paste it into your script:

```
library(graphics)
plot(co2, ylab = "CO2 (ppm)", las = 1)
title(main = "Mauna Loa Atmospheric CO2 Concentration")
```

- select all by pressing **Ctrl + A**
- Then run the code by pressing the **Run** Button or **Ctrl + Enter**

You should now get your first visualization:



As you probably noticed, we did not load any data. The basic installation of “R” and some packages come with test data. So that is an easy way to test something. The R Dataset Package provides some preinstalled datasets, including the used “Mauna Loa Atmospheric CO2 Concentration” dataset.

# **Part I**

## **R Basics**



## Chapter 3

# Introduction to R Basics

The following chapters of the part “R-Basics” is a short overview of the fundamental principles for understanding the code presented in the recipes in part “Data Visualizations”. It focuses on practical examples of how data can be loaded, transformed and analyzed.

It is not the goal of this book to fully introduce beginners to the programming language “R” and the environment in general. There are many really good sources where you can familiarize yourself with “R” if needed.

Two sources are recommended to facilitate the introduction to “R” and to learn the relevant basics. Choose one that suits you and go through the recommended chapter:

- Introduction to Data Science - Chapter 2 “R Basics”
- Engineering Data Analysis in R - Chapter 2 “The R Programming Environment”

Throughout the book, reference is made to these two continuative sources and you only need to read the one that appeals to you more. In the referenced chapters, these cover similar content.



# Chapter 4

## Loading Data

This chapter introduces two functions that can be used to load data from csv-files and Excel-files.

Experienced readers will find more information about data imports here:

- Introduction to Data Science - Chapter 5 “Importing data”
- [Engineering Data Analysis in R - Chapter 3 “Getting and Cleaning Data”][https://smogdr.github.io/edar\\_coursebook/rprog2.html](https://smogdr.github.io/edar_coursebook/rprog2.html){target=”\_blank”}

csv-Files

Load data from comma separated files

```
# read data from current folder
df <- read.csv("datafile.csv")

# read data from a specific folder
df <- read.csv("C:/Desktop/datafile.csv")

# read data from a file in the internet
df <- read.csv2("https://github.com/hslu-ige-laes/edar/raw/master/sampleData/flatElectricity.csv")

# add arguments on how to parse the content
df <- read.csv("datafile.csv",
              header=FALSE,
              stringsAsFactors=FALSE,
              sep =",",
              na.strings = c("", "NA"))
```

Attention: By default, strings in the data are treated as factors, so add `stringsAsFactors=FALSE`

Set your cursor to the function name `read.csv()` and press F1. Then you get in R Studio bottom right in the tab Help information about other function arguments you can use.

Note that the function `read.csv()` has the default `sep = ","` and `read.csv2()` has the default `sep = ";"`

### Excel-Files

Load data from `*.xlsx` Excel files:

```
# Only need to install once
install.packages("xslx")

library(xslx)

df <- read.xlsx("datafile.xlsx", 1)
df <- read.xlsx("datafile.xlsx", sheetIndex=2)
df <- read.xlsx("datafile.xlsx", sheetName="Revenues")

# show the first lines of the so called "data frame"
head(df)
```

For reading older Excel files in the .xls format, the gdata package has the function `read.xls()`:

```
# Only need to install once
install.packages("gdata")

library(gdata)

df <- read.xls("datafile.xls") # Read first sheet
df <- read.xls("datafile.xls", sheet=2) # Read second sheet
```

Both the xlsx and gdata packages require other software to be installed on your computer. For xlsx, you need to install Java on your machine. For gdata, you need Perl, which comes as standard on Linux and Mac OS X, but not Windows. On Windows, you'll need ActiveState Perl. The Community Edition can be obtained for free.

## Chapter 5

# Data Wrangling

This chapter gives an overview of the most important data manipulation functions used throughout this book.

Experienced readers will find more information about data imports here:

- Introduction to Data Science - Chapter 4 “The tidyverse”
- Engineering Data Analysis in R - Chapter 3.5 “Data Cleaning”
- Engineering Data Analysis in R - Chapter 3.6 “Piping”

It is a fact that the data import and manipulation part of analyses often takes more time than the actual analysis or visualization itself. This is because the exchange data formats are not standardized and meters and sensors record at different time intervals. Data quality, missing data, data imputation and data cleansing also play a major role.

## 5.1 Add Metadata for later filtering

Firstly we have to load a dataset into a dataframe:

```
# load data set
df <- read.csv("https://github.com/hslu-ige-laes/edar/raw/master/sampleData/centralOutsideTemp.csv",
               stringsAsFactors=FALSE,
               sep =";")
```

### 5.1.1 Year, Month, Day, Day of Week

To e.g. group, filter and aggregate data we need eventually the date splitted up in day, month and year:

```
library(dplyr)
library(lubridate)

df$time <- parse_date_time(df$time, "YmdHMS", tz = "Europe/Zurich")
df$year <- as.Date(cut(df$time, breaks = "year"))
df$month <- as.Date(cut(df$time, breaks = "month"))
df$day <- as.Date(cut(df$time, breaks = "day"))
df$weekday <- wday(df$time,
                     label = TRUE,
                     locale = "English",
                     abbr = TRUE,
                     week_start = getOption("lubridate.week.start", 1))
```

This code first parses the timestamp with a specific timezone. Then three columns are added.

Please note that the month also contains the year and a day. This is useful for a later step where you can group the series afterwards.

```
head(df, 2)

##           time centralOutsideTemp
## 1 2018-03-21 11:00:00      5.2
## 2 2018-03-21 12:00:00      6.7

tail(df, 2)

##           time centralOutsideTemp
## 21864 2020-09-17 10:00:00     26.65
## 21865 2020-09-17 11:00:00     28.10
```

### 5.1.2 Season of Year

For some analyses it is useful to color single points of a scatterplot according to the season. For this we need to have the season in a separate column:

```
library(redutils)
# get season from a date
getSeason(as.Date("2019-04-01"))

## [1] "Spring"
```

If you want to change the language, you can give the function dedicated names for the season:

```
getSeason(as.Date("2019-04-01"),
          seasonlab = c("Winter", "Frühling", "Sommer", "Herbst"))

## [1] "Frühling"
```

To apply this function to a whole dataframe we can use the dplyr mutate function. The code below creates a new column named “season”:

```
df <- dplyr::mutate(df, season = getSeason(df$time))

head(df, 1)

##           time centralOutsideTemp season
## 1 2018-03-21 11:00:00          5.2 Spring

tail(df, 1)

##           time centralOutsideTemp season
## 21865 2020-09-17 11:00:00        28.1 Fall
```

## 5.2 Manipulating Data Frames

The `dplyr` package from the `tidyverse` introduces functions that perform some of the most common operations when working with data frames and uses names for these functions that are relatively easy to remember.

### 5.2.1 Change Row Names

```
# rename columns
names(df) <- c("timestamp", "humidity", "temp_c")
```

### 5.2.2 Adding a column with `mutate()`

```
library(dplyr)

# add new column with temperature conversion from celsius to fahrenheit
df <- mutate(df, temp_f = temp_c * 1.8 + 32)

# This code does the same, but only with a pipe
df <- df %>%
  mutate(temp_f = temp_c * 1.8 + 32)
```

### 5.2.3 Subsetting with `filter()`

```
library(dplyr)

# add new column with temperature conversion from celsius to fahrenheit
df <- filter(df,
  timestamp >= "2020-01-01 00:00:00",
  timestamp <= "2020-12-31 23:45:00")

df.high <- filter(df, temp_c > 30)
```

Note: Whether you put the whole code on one line or split it after a comma does not have an effect on the computation, it is only more readable when the lines aren't too wide.

### 5.2.4 Add/remove columns with `select()`

```
library(dplyr)

# Based on the upper example we remove the celsius column after calculation
df <- select(df, -temp_c)

# Create new data frame
df.new <- select(df, timestamp, temp_f)

# use select() in a so called dplyr pipe
df <- df %>%
  mutate(df, temp_f = temp_c * 1.8 + 32) %>%
  select(-temp_c)
```

## 5.2.5 The pipe %>%

With the package `dplyr` we can perform a series of operations, for example select and then filter, by sending the results of one function to another using what is called the pipe operator: `%>%`.

Details can be found in Introduction to Data Science - Chapter 4.5

### 5.2.6 Wide to Long

```
values_to = "value",
values_drop_na = TRUE))
```

```
# long format
head(df.long, 16)
```

```
##               time      sensor value
## 1 2018-10-03 00:00:00 FlatA_Hum 53.00
## 2 2018-10-03 00:00:00 FlatA_Temp 24.43
## 3 2018-10-03 00:00:00 FlatB_Hum 38.80
## 4 2018-10-03 00:00:00 FlatB_Temp 22.40
## 5 2018-10-03 00:00:00 FlatC_Hum 44.00
## 6 2018-10-03 00:00:00 FlatC_Temp 24.50
## 7 2018-10-03 00:00:00 FlatD_Hum 49.00
## 8 2018-10-03 00:00:00 FlatD_Temp 24.43
## 9 2018-10-03 01:00:00 FlatA_Hum 53.00
## 10 2018-10-03 01:00:00 FlatA_Temp 24.40
## 11 2018-10-03 01:00:00 FlatB_Hum 38.80
## 12 2018-10-03 01:00:00 FlatB_Temp 22.40
## 13 2018-10-03 01:00:00 FlatC_Hum 44.00
## 14 2018-10-03 01:00:00 FlatC_Temp 24.50
## 15 2018-10-03 01:00:00 FlatD_Hum 49.00
## 16 2018-10-03 01:00:00 FlatD_Temp 24.40
```

### 5.2.7 Long to Wide

```
# long format
head(df.long)
```

```
##               time      sensor value
## 1 2018-10-03 00:00:00 FlatA_Hum 53.00
## 2 2018-10-03 00:00:00 FlatA_Temp 24.43
## 3 2018-10-03 00:00:00 FlatB_Hum 38.80
## 4 2018-10-03 00:00:00 FlatB_Temp 22.40
## 5 2018-10-03 00:00:00 FlatC_Hum 44.00
## 6 2018-10-03 00:00:00 FlatC_Temp 24.50
```

```
# convert long table into wide table
df.wide <- as.data.frame(tidy::pivot_wider(df.long,
                                              names_from = "sensor",
                                              values_from = "value"))
)
```

```
# wide format
head(df.wide)
```

```
##               time FlatA_Hum FlatA_Temp FlatB_Hum FlatB_Temp FlatC_Hum
## 1 2018-10-03 00:00:00      53.0      24.43      38.8      22.40      44.0
## 2 2018-10-03 01:00:00      53.0      24.40      38.8      22.40      44.0
## 3 2018-10-03 02:00:00      53.0      24.40      39.3      22.40      44.7
## 4 2018-10-03 03:00:00      53.0      24.40      40.3      22.40      45.0
```

```

## 5 2018-10-03 04:00:00      53.3    24.40    41.0    22.37    45.2
## 6 2018-10-03 05:00:00      53.7    24.40    41.2    22.30    47.2
##   FlatC_Temp FlatD_Hum FlatD_Temp
## 1      24.50     49.0    24.43
## 2      24.50     49.0    24.40
## 3      24.50     48.3    24.38
## 4      24.50     48.0    24.33
## 5      24.50     47.7    24.30
## 6      24.57     47.2    24.30

```

### 5.2.8 Merge two Dataframes

```

library(dplyr)
library(lubridate)

# read file one and parse dates
dfOutsideTemp <- read.csv("https://github.com/hslu-ige-laes/edar/raw/master/sampleData/centralOutsideTemp.csv",
                           stringsAsFactors=FALSE,
                           sep =";")

dfOutsideTemp$time <- parse_date_time(dfOutsideTemp$time,
                                         orders = "YmdHMS",
                                         tz = "Europe/Zurich")

# read file two and parse dates
dfFlatTempHum <- read.csv("https://github.com/hslu-ige-laes/edar/raw/master/sampleData/flatTempHum.csv",
                           stringsAsFactors=FALSE, sep =";")

dfFlatTempHum$time <- parse_date_time(dfFlatTempHum$time,
                                         order = "YmdHMS",
                                         tz = "Europe/Zurich")

# merge the two files into a new data frame and keep only rows where all values are available
df <- merge(dfOutsideTemp, dfFlatTempHum, by = "time") %>% na.omit()

head(df)

##           time centralOutsideTemp FlatA_Hum FlatA_Temp FlatB_Hum
## 1 2018-10-03 00:00:00      11.80      53.0    24.43     38.8
## 2 2018-10-03 01:00:00      11.25      53.0    24.40     38.8
## 3 2018-10-03 02:00:00      11.45      53.0    24.40     39.3
## 4 2018-10-03 03:00:00      11.40      53.0    24.40     40.3
## 5 2018-10-03 04:00:00      11.10      53.3    24.40     41.0
## 6 2018-10-03 05:00:00      11.05      53.7    24.40     41.2
##   FlatB_Temp FlatC_Hum FlatC_Temp FlatD_Hum FlatD_Temp
## 1      22.40     44.0    24.50     49.0    24.43
## 2      22.40     44.0    24.50     49.0    24.40
## 3      22.40     44.7    24.50     48.3    24.38
## 4      22.40     45.0    24.50     48.0    24.33
## 5      22.37     45.2    24.50     47.7    24.30
## 6      22.30     47.2    24.57     47.2    24.30

```



# Chapter 6

## Explorative Data Analysis

Explorative Data Analysis (EDA) is a technique based on the human characteristic of visual pattern recognition. The purpose of EDA is simple: to learn more about data by visualizing it in different ways. John W. Tukey, considered the founder of exploratory data analysis, once wrote:

“Exploratory data analysis is graphical detective work.” - John W. Tukey

### 6.1 Get Overview of Data

A first step is getting an overview of the whole data set and specific series of it.

#### 6.1.1 Load data

Load test data set in a data frame (e.g. from a csv-file)

```
## Warning: 3 failed to parse.
```

#### 6.1.2 Names

Show the column headers of a data frame

```
names(df)
```

```
## [1] "time"          "energyHeatingMeter" "supplyTempHeating"
```

### 6.1.3 Structure

Show the structure of the data frame

```
str(df)
```

```
## 'data.frame':    22317 obs. of  3 variables:
## $ time           : POSIXct, format: "2018-03-03 00:00:00" "2018-03-03 01:00:00" ...
## $ energyHeatingMeter: num  45020 NA NA NA NA ...
## $ supplyTempHeating : num  24.7 24.1 23.7 23.4 31.6 ...
```

### 6.1.4 Head/Tail

Show the first and last values

```
head(df)
```

```
##               time energyHeatingMeter supplyTempHeating
## 1 2018-03-03 00:00:00          45019.81        24.73
## 2 2018-03-03 01:00:00             NA        24.06
## 3 2018-03-03 02:00:00             NA        23.73
## 4 2018-03-03 03:00:00             NA        23.45
## 5 2018-03-03 04:00:00             NA        31.59
## 6 2018-03-03 05:00:00             NA        29.14
```

```
tail(df)
```

```
##               time energyHeatingMeter supplyTempHeating
## 22312 2020-09-17 15:00:00             NA            NA
## 22313 2020-09-17 16:00:00             NA            NA
## 22314 2020-09-17 17:00:00             NA            NA
## 22315 2020-09-17 18:00:00             NA            NA
## 22316 2020-09-17 19:00:00             NA            NA
## 22317 2020-09-17 20:00:00             NA            NA
```

Note: if you want to show only the first three entries, you can type  
`head(df, 3)`

### 6.1.5 Five number summary

Reveals details like object classes

```
summary(df$supplyTempHeating)
```

```
##   Min. 1st Qu. Median   Mean 3rd Qu.   Max. NA's
## 18.37  23.35  24.61  25.72  27.49  44.68  362
```

## 6.2 Quickly Exploring Data

Please refer to the R Graphics Cookbook from Winston Chang - Chapter 2 “Quickly Exploring Data”.

This is a great resource where you can find everything you need to know about creating basic plots.



## **Part II**

# **Data Visualizations**



# Chapter 7

## Seasonal Plots

Seasonal plots are a graphical tool to visualize and detect seasonality in a time series. Based on a selected periodicity it emphasizes the seasonal patterns and also shows the changes in seasonality over time. Especially, it allows to detect changes between different seasons.

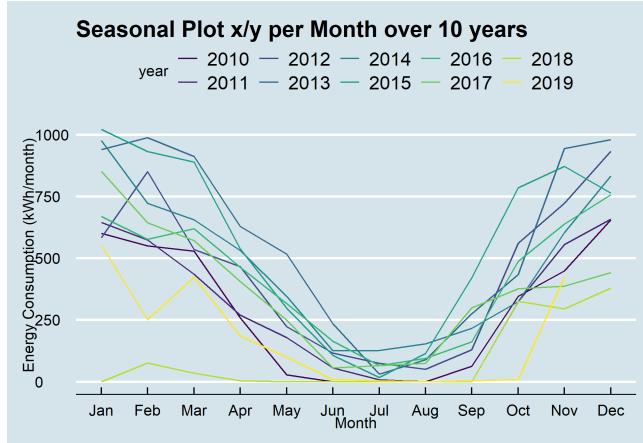


Figure 7.1: Seasonal Plot Overlapping per Month over 10 Years

However, such plots are only useful if the period of the seasonality is already known. In many cases, this will in fact be known. For example, monthly data typically has a period of 12. If the period is not known, an autocorrelation plot or spectral plot can be used to determine it.

This chapter shows some useful types of seasonal plots.

## 7.1 Overlapping

### 7.1.1 Goal

Plot a seasonal plot as described in Hyndman and Athanasopoulos (2014, chapter 2.4):

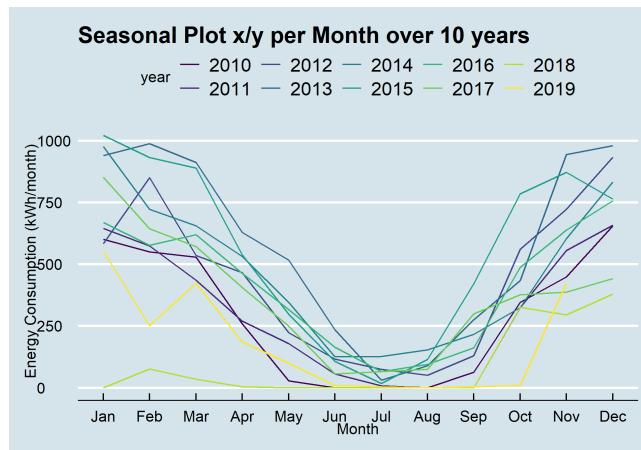


Figure 7.2: Seasonal Plot Overlapping per Month over 10 Years

This is like a standard time series plot except that the data are plotted against the “seasons” for each year and are overlapping. Be aware that seasons in this context don’t correlate with the seasons of the year.

### 7.1.2 Data Basis

In general, the values of energy meters, as in our example, increase steadily:

### 7.1.3 Solution

Create a new script, copy/paste the following code and run it:

```
library(forecast)
library(dplyr)
library(plotly)
library(htmlwidgets)
library(ggthemes)
library(viridis)
library(lubridate)

# load csv file
df <- read.csv2("https://github.com/hslu-ige-laes/edar/raw/master/sampleData/flatHeatAndHotWater.csv",
```

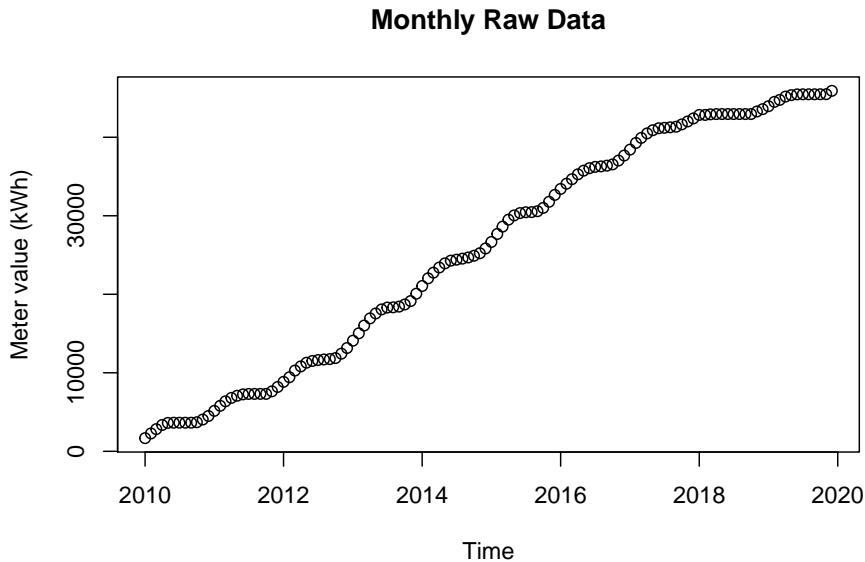


Figure 7.3: Raw Data for Seasonal Plot Overlapping

```

stringsAsFactors=FALSE)

# filter flat
df <- df %>% select(timestamp, Adr02_energyHeat)

colnames(df) <- c("timestamp", "meterValue")

# calculate consumption value per month
# pay attention, the value of 2010-02-01 00:00:00 represents the meter reading on february first,
# so the consumption for february first is value(march) - value(february) !
df <- df %>% mutate(value = lead(meterValue) - meterValue)

# remove counter value column
df <- df %>% select(-meterValue)

# value correction (outlier because of commissioning)
df[1, 2] <- 600

# create time series object for ggseanplot function
df.ts <- ts(df %>% select(value) %>% na.omit(), frequency = 12, start = min(year(df$timestamp)))

# create x/y plot
numYears = length(unique(year(df$timestamp))) # used for colours

plot <- ggseasonplot(df.ts,
                      col = viridis(numYears),
                      main = "Seasonal Plot x/y per Month over 10 years",

```

```

    ylab = "Energy Consumption (kWh/month)"
  )

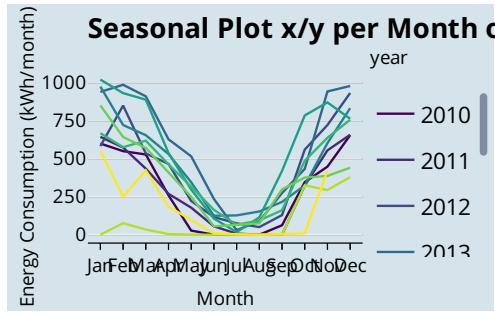
# show static plot (uncomment it if you want a static plot)
#plot

# change theme (optional)
plot <- plot + ggthemes::theme_economist()

# make plot interactive (optional)
plotly <- plotly::ggplotly(plot)

# show plot interactive plot (optional)
plotly

```



```

# save static plot as png (optional)
ggsave("images/plotSeasonalXY.png", plot)

# save interactive plot as html (optional)
library(htmlwidgets)
htmlwidgets::saveWidget(plotly, "plotlySeasonalXY.html")

```

#### 7.1.4 Discussion

A seasonal plot allows the underlying seasonal pattern to be seen more clearly, and is especially useful in identifying years in which the pattern changes.

Hints:

- in the interactive version you can double-click on year in the legend, then only this year is visible
- click once to activate/deactivate a year

## 7.2 Mini Plots

### 7.2.1 Goal

Plot a seasonal month plot as described in Hyndman and Athanasopoulos (2014, chapter 2.5):

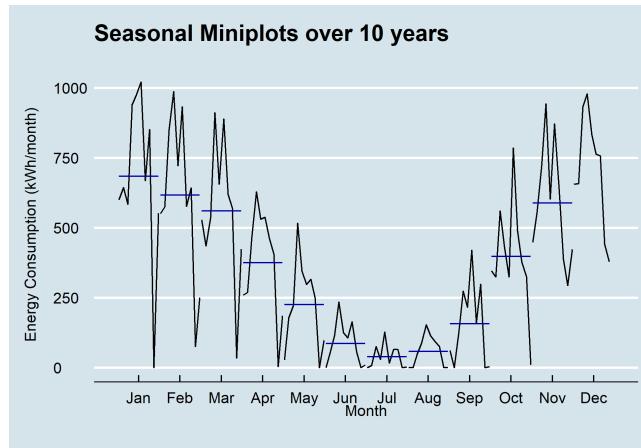


Figure 7.4: Seasonal Plot with mini Time Plots over 10 Years

Here the seasonal patterns for each season are collected together in separate mini time plots. Be aware that seasons in this context don't correlate with the seasons of the year.

### 7.2.2 Data Basis

In general, the values of energy meters, as in our example, increase steadily:

### 7.2.3 Solution

Create a new script, copy/paste the following code and run it:

```
library(forecast)
library(dplyr)
library(plotly)
library(htmlwidgets)
library(ggthemes)
library(viridis)
library(lubridate)

# load csv file
df <- read.csv2("https://github.com/hslu-ige-laes/edar/raw/master/sampleData/flatHeatAndHotWater.csv",
```

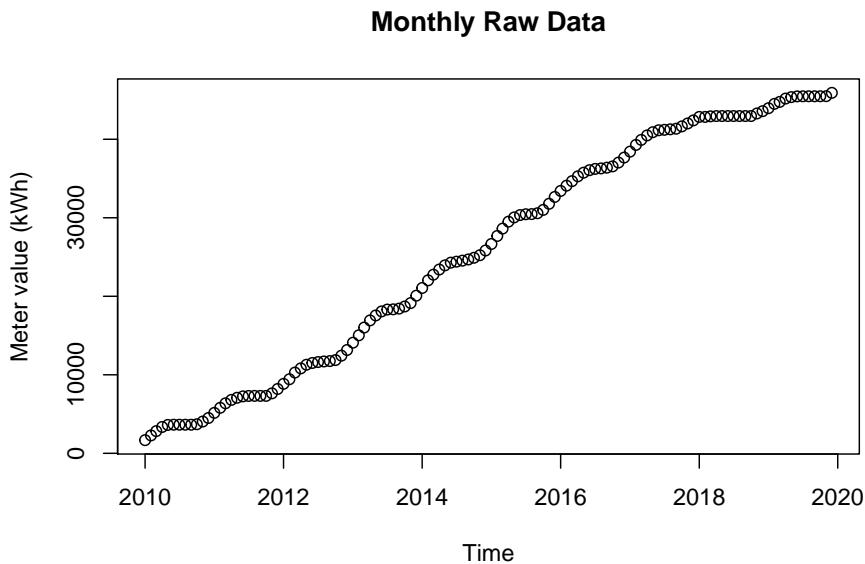


Figure 7.5: Raw Data for Seasonal Miniplots

```

stringsAsFactors=FALSE)

# filter flat
df <- df %>% select(timestamp, Adr02_energyHeat)

colnames(df) <- c("timestamp", "meterValue")

# calculate consumption value per month
# pay attention, the value of 2010-02-01 00:00:00 represents the meter reading on february first,
# so the consumption for february first is value(march) - value(february) !
df <- df %>% mutate(value = lead(meterValue) - meterValue)

# remove counter value column
df <- df %>% select(-meterValue)

# value correction (outlier because of commissioning)
df[1, 2] <- 600

# create time series object for ggmonthplot function
df.ts <- ts(df[-1], frequency = 12, start = min(year(df$timestamp)))

# create x/y plot

numYears = length(unique(year(df$timestamp)))

plot <- ggmonthplot(df.ts,
                     col = viridis(numYears),

```

```

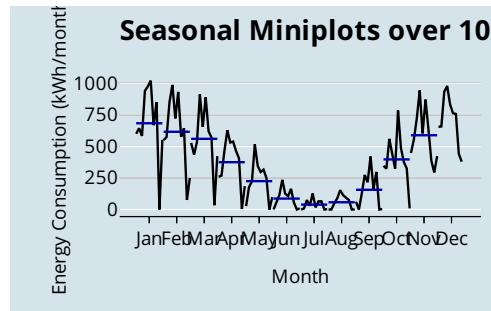
    main = "Seasonal Miniplots over 10 years\n",
    ylab = "Energy Consumption (kWh/month)\n",
    xlab = "Month\n"
  )

# change theme (optional)
plot <- plot + ggthemes::theme_economist()

# make plot interactive (optional)
plotly <- plotly::ggplotly(plot)

# show plot
plotly

```



```

# save static plot as png
ggsave("images/plotSeasonalMiniplots.png", plot)

# save interactive plot as html
library(htmlwidgets)
htmlwidgets::saveWidget(plotly, "plotlySeasonalMiniplots.html")

```

#### 7.2.4 Discussion

- This type of seasonal plot shows the mean value of each month and therefore emphasises on the monthly comparison

- It revelas as well the mean seasonal pattern with the blue lines

## 7.3 Polar

### 7.3.1 Goal

Plot a seasonal plot as described in Hyndman and Athanasopoulos (2014, chapter 2.4):

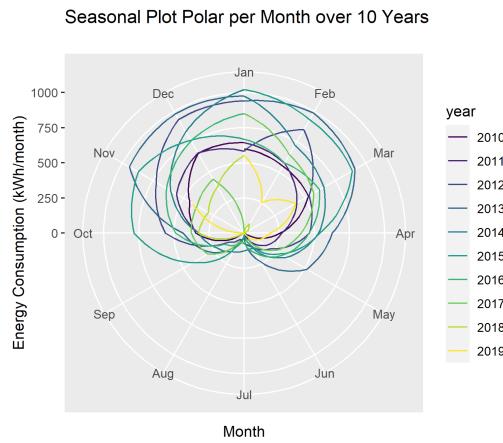


Figure 7.6: Seasonal Plot Polar per Month over 10 Years

This is like an overlapping time series plot which uses polar coordinates. Be aware that seasons in this context don't correlate with the seasons of the year.

### 7.3.2 Data Basis

In general, the values of energy meters, as in our example, increase steadily:

### 7.3.3 Solution

Create a new script, copy/paste the following code and run it:

```
library(forecast)
library(dplyr)
library(plotly)
library(htmlwidgets)
library(ggthemes)
library(viridis)
library(lubridate)

# load csv file
df <- read.csv2("https://github.com/hslu-ige-laes/edar/raw/master/sampleData/flatHeatAndHotWater.csv",
                stringsAsFactors=FALSE)
```

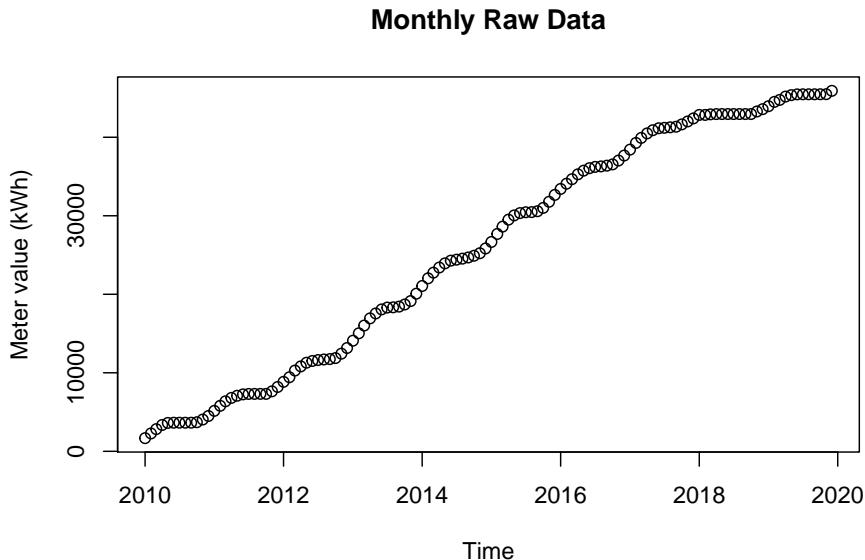


Figure 7.7: Raw Data for Seasonal Plot Polar

```

# filter flat
df <- df %>% select(timestamp, Adr02_energyHeat)

colnames(df) <- c("timestamp", "meterValue")

# calculate consumption value per month
# pay attention, the value of 2010-02-01 00:00:00 represents the meter reading on february first,
# so the consumption for february first is value(march) - value(february) !
df <- df %>% mutate(value = lead(meterValue) - meterValue)

# remove counter value column
df <- df %>% select(-meterValue)

# value correction (outlier because of commissioning)
df[1,2] <- 600

df.ts <- ts(df %>% select(value) %>% na.omit(), frequency = 12, start = min(year(df$timestamp)))

# create polar plot

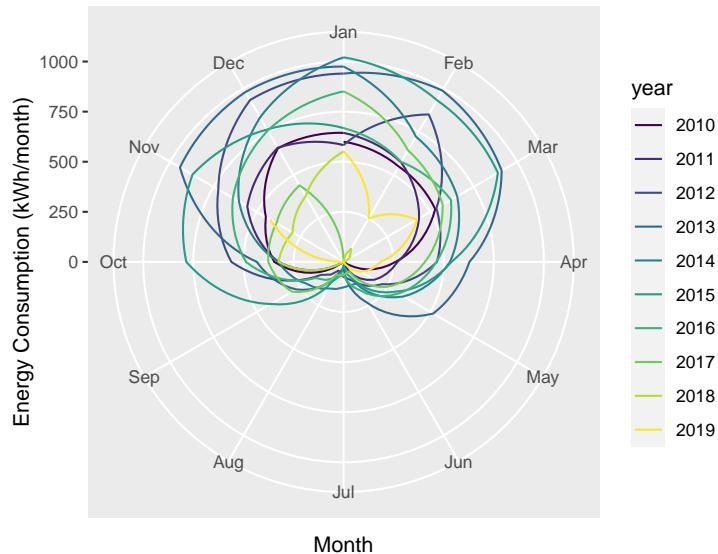
numYears = length(unique(year(df$timestamp)))

plot <- ggseasonplot(df.ts,
                      col = viridis(numYears),
                      main = "Seasonal Plot Polar per Month over 10 Years\n",
                      ylab = "Energy Consumption (kWh/month)",
                      polar = TRUE

```

```
)
# show plot (interactive version with plotly unfortunately not possible)
plot
```

Seasonal Plot Polar per Month over 10 Years



```
# save static plot as png (optional)
ggsave("images/plotSeasonalPolar.png", plot)
```

### 7.3.4 Discussion

This representation emphasizes the high consumption in summer very well, which could undoubtedly be reduced in a residential building. The Years 2018 and 2019 show, that this optimization was done.

To emphasize this optimization please refer to the next chapter 7.4.

## 7.4 Before/After Optimization

### 7.4.1 Goal

To highlight an energy optimization in a season diagram, we can gray out the seasons before the optimization and only highlight the monthly values after the optimization. To better quantify the success, we can calculate and display the confidence interval of the years before.

In the following we will create the following plot:

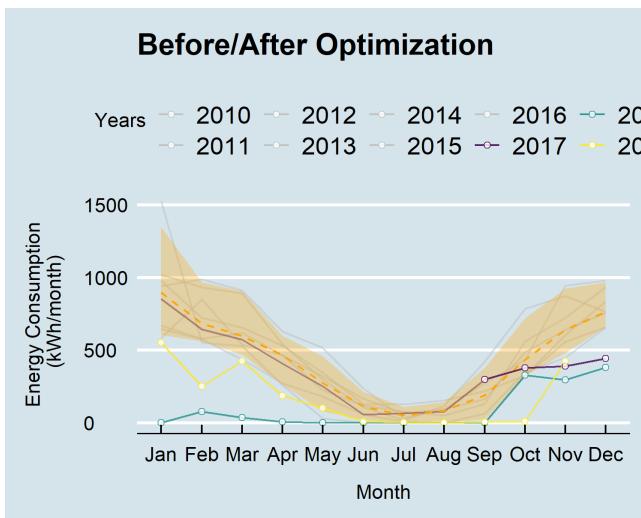


Figure 7.8: Seasonal Plot Overlapping Before/After

### 7.4.2 Data Basis

In general, the values of energy meters, as in our example, increase steadily:

### 7.4.3 Solution

Create a new script, copy/paste the following code and run it:

```
library(redutils)
library(dplyr)
library(plotly)
library(htmlwidgets)
library(ggthemes)

# load csv file
```

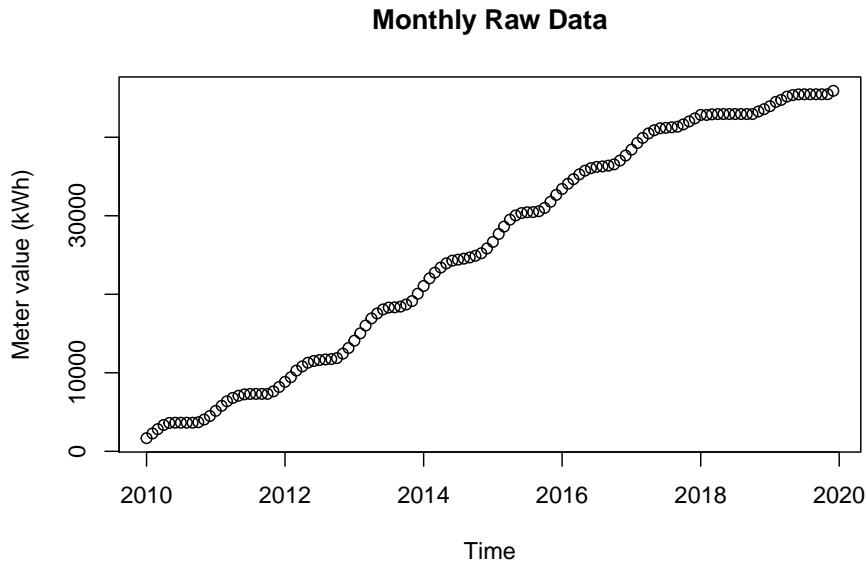


Figure 7.9: Raw Data for Seasonal Plot Overlapping Before/After Optimization

```
df <- read.csv("https://github.com/hslu-ige-laes/edar/raw/master/sampleData/flatHeatAndHotWater.csv",
               stringsAsFactors=FALSE)

# filter flat
df <- df %>% select(timestamp, Adr02_energyHeat)

colnames(df) <- c("timestamp", "meterValue")

# calculate consumption value per month
# pay attention, the value of 2010-02-01 00:00:00 represents the meter reading on february first,
# so the consumption for february first is value(march) - value(february) !
df <- df %>% mutate(value = lead(meterValue) - meterValue)

# remove counter value column
df <- df %>% select(-meterValue)

# value correction (outlier because of commissioning)
df[1,2] <- 600

# create plot
plot <- plotSeasonalXYBeforeAfter(df,
                                    dateOptimization = "2017-09-01",
                                    locTimeZone = "Europe/Zurich",
                                    main = "Before/After Optimization",
                                    ylab = "Energy Consumption \n(kWh/month")
)
```

```
# change theme (optional)
plot <- plot + ggthemes::theme_economist()

# make plot interactive (optional)
plotly <- plotly::ggplotly(plot)

# show plot
plotly
```



```
# save static plot as png (optional)
ggsave("images/plotSeasonalXYBeforeAfter.png", plot)

# save interactive plot as html (optional)
library(htmlwidgets)
htmlwidgets::saveWidget(plotly, "plotlySeasonalXYBeforeAfter.html")
```

#### 7.4.4 Discussion

- One can clearly see the impact of the optimization in mid-2017
- And as well the too low setting of January 2018 where the thermostat of the flat got deactivated
- The confidence band shows as well the year 2013 which had an unusual high consumption from February to June



## Chapter 8

# Time Series Decomposition

Typical time series result from the interaction of regular and random causes. The regular causes can vary periodically (seasonally) and/or contain long-term trends. Random influences are often called noise.

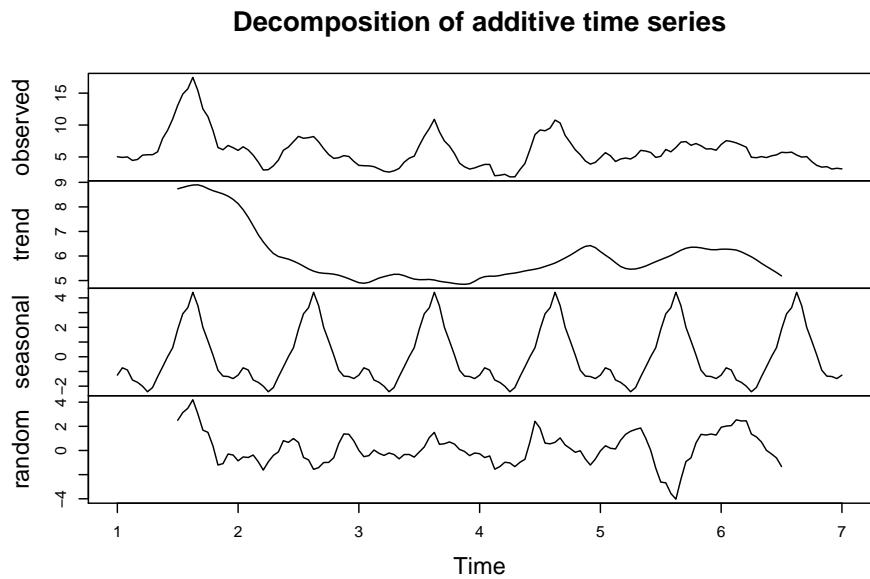
Decomposition deconstructs time series into its components “trend”, “seasonality” and “randomness.” For further data analysis it is often necessary to decompose the trend and the seasonal component from the raw data. Therefore, a large part of the time series analyses deals with corresponding procedures. Sometimes the remaining Randomness is of interest and sometimes a detrended series as in chapter 10.4.

**Trend Component** The trend component of a time series refers to the general direction in which the time series is moving in the long term. Time series can have a positive or a negative trend, but can also have no trend. A trend exists when there is a persistent increasing and/or decreasing direction in the data.

**Seasonal Component** The seasonal component for time series data refers to its tendency to rise and fall at consistent frequencies. Seasonality occurs over a fixed and known period (e.g., the quarter of the year, the month, or day of the week).

**Random/Remainder/Irregular Component** The remainder is what’s left of the time series data after removing its trend and seasonal components. It is the random fluctuation in the time series data that the above components cannot explain.

An exemplary decomposition of an outside temperature time series over 7 days:



This chapter shows how a time series can be decomposed and presented interactively.

## 8.1 Long term

### 8.1.1 Goal

Decompose a long term time series of ten years monthly data.

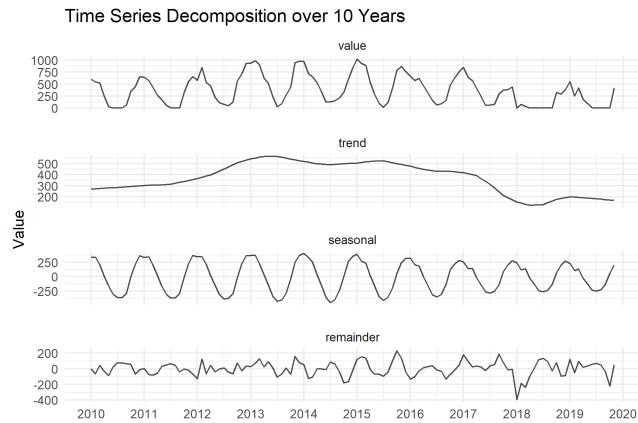


Figure 8.1: Decomposition of long time series over 10 Years

### 8.1.2 Data Basis

In general, the values of energy meters, as in our example, increase steadily:

### 8.1.3 Solution

Create a new script, copy/paste the following code and run it:

```
library(dplyr)
library(lubridate)
library(plotly)
library(ggplot2)
library(forecast)

# load csv file
df <- read.csv2("https://github.com/hslu-ige-laes/edar/raw/master/sampleData/flatHeatAndHotWater.csv",
                 stringsAsFactors=FALSE)

# filter flat
df <- df %>% select(timestamp, Adr02_energyHeat)

colnames(df) <- c("Time", "meterValue")
```

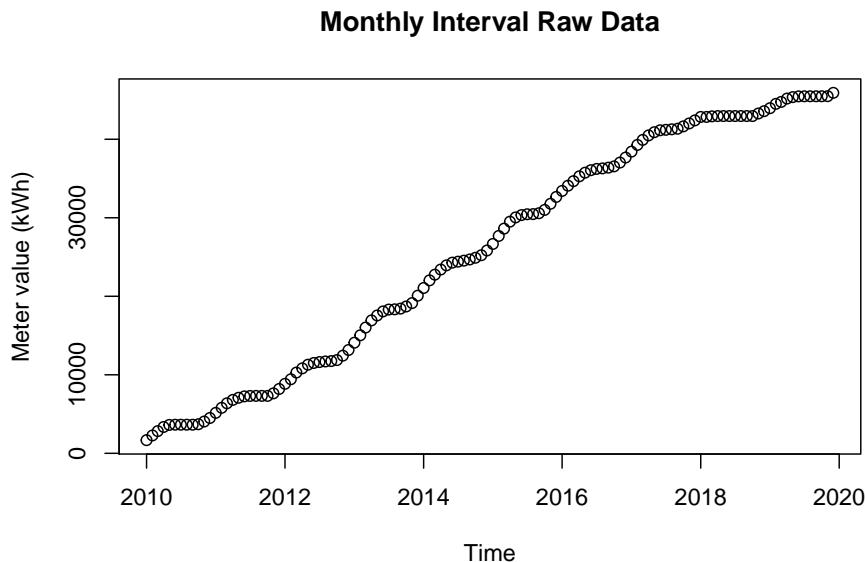


Figure 8.2: Raw Data for Decomposition Plot Long Term

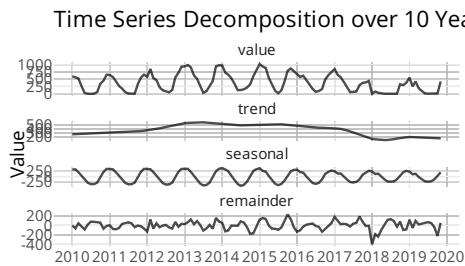
```

    values_to = "Value",
    values_drop_na = TRUE)
)
data$component <- as.factor(data$Component)
data$component <- factor(data$Component, c("value",
                                             "trend",
                                             "seasonal",
                                             "remainder")))
data$Value <- round(data$Value, digits = 1)

plot <- ggplot(data) +
  geom_path(aes(x = Time,
                 y = Value
               )),
  color = "black",
  alpha = 0.7) +
  facet_wrap(~component, ncol = 1, scales = "free_y") +
  scale_x_datetime(date_breaks = "years" , date_labels = "%Y") +
  theme_minimal() +
  theme(panel.spacing = unit(1, "lines"),
        legend.position = "none") +
  labs(x = "") +
  ggtitle("Time Series Decomposition over 10 Years")

ggplotly(plot)

```



```

# save static plot as png (optional)
ggsave("images/plotDecompositionLong.png", plot)

```

#### 8.1.4 Discussion

- Energy optimization in mid-2017 is clearly visible in the trend and also in the magnitude of the seasonal pattern
- And as well in the remainder the too low setting of January 2018 where the thermostat of the flat got deactivated
- The trend shows as well an higher consumption in June 2013

## 8.2 Short term

### 8.2.1 Goal

Decompose a short term time series of e.g. 5 days 15min data.

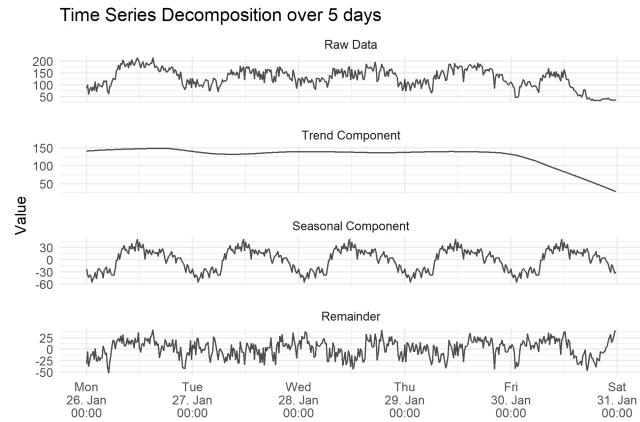


Figure 8.3: Seasonal Plot Overlapping per Month over 10 Years

### 8.2.2 Data Basis

In general, the values of energy meters, as in our example, increase steadily:

### 8.2.3 Solution

Create a new script, copy/paste the following code and run it:

```
library(dplyr)
library(lubridate)
library(plotly)
library(ggplot2)
library(forecast)

# change language to English, otherwise weekdays are in local language
Sys.setlocale("LC_TIME", "English")

## [1] "English_United States.1252"
```

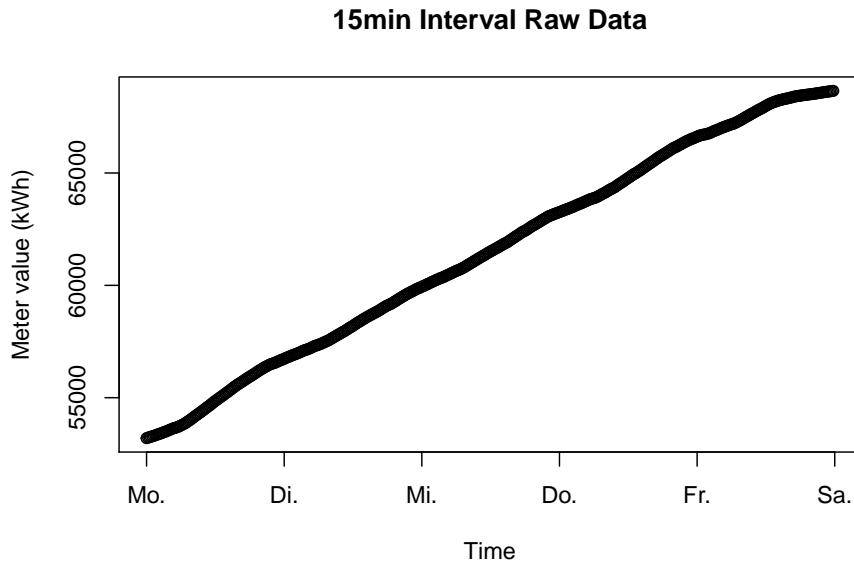


Figure 8.4: Raw Data for Decomposition Plot Short Term

```
# load time series data
df <- read.csv("https://github.com/hslu-ige-laes/edar/raw/master/sampleData/eboBookEleMeter.csv",
               stringsAsFactors=FALSE,
               sep =";")

# rename column names
colnames(df) <- c("time", "meterValue")

df$time <- parse_date_time(df$time,
                           orders = "YmdHMS",
                           tz = "Europe/Zurich")
df$time <- force_tz(df$time, tzzone = "UTC")

# uncomment to filter time range if necessary
#df <- df %>% filter(Time > "2015-03-01 00:00:00", Time < "2015-04-01 00:00:00")

# Fill missing values with NA
grid.df <- data.frame(time = seq(min(df$time, na.rm = TRUE),
                                 max(df$time, na.rm = TRUE),
                                 by = "15 mins"))
df <- merge(df, grid.df, all = TRUE)

# convert steadily counting energy meter value from kWh to power in kW
df <- df %>%
  mutate(value = (meterValue - lag(meterValue))*4) %>%
  select(-meterValue) %>%
  na.omit()
```

```

# remove negative values which occur because of change summer/winter time
df <- df %>% filter(value >= 0)

# select time range
df <- df %>% filter(time >= as.POSIXct("2015-01-26 00:00:00", tz = "UTC"),
                      time < as.POSIXct("2015-01-31 00:00:00", tz = "UTC"))

# ===== Start of Code =====
df.ts <- ts(df %>% select(value) %>% na.omit(),
            frequency = 96)

df.decompose <- df.ts[,1] %>%
  stl(s.window = 193)

df.decompose <- df.decompose$time.series

df.decompose <- as.data.frame(df.decompose)

df.decompose <- cbind(df, df.decompose)

data <- as.data.frame(tidyrr::pivot_longer(df.decompose,
                                             cols = -time,
                                             names_to = "component",
                                             values_to = "value",
                                             values_drop_na = TRUE))
)
data$component <- as.factor(data$component)
data$component <- factor(data$component, c("value",
                                            "trend",
                                            "seasonal",
                                            "remainder"))

# prepare data for plot

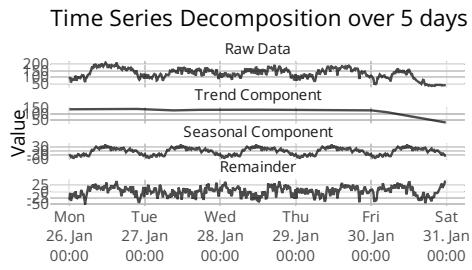
componentTitles = c("Raw Data", "Trend Component", "Seasonal Component", "Remainder")

data <- data %>%
  mutate(component = recode(component,
                            value = componentTitles[1],
                            trend = componentTitles[2],
                            seasonal = componentTitles[3],
                            remainder = componentTitles[4]),
         value = round(data$value, digits = 1)) %>%
  rename(Value = value,
        Time = time)

plot <- ggplot(data) +
  geom_path(aes(x = Time,
                y = Value
               ),
            color = "black",
            alpha = 0.7) +
  facet_wrap(~component, ncol = 1, scales = "free_y") +
  scale_x_datetime(date_breaks = "days" , date_labels = "%a\n%d. %b\n%H:%M") +
  theme_minimal() +
  theme(panel.spacing = unit(1, "lines"),
        legend.position = "none") +

```

```
  labs(x = "") +  
  ggtitle("Time Series Decomposition over 5 days")  
  
  ggsave(plot)
```



```
# save static plot as png (optional)  
ggsave("images/plotDecompositionShort.png", plot)
```

# Chapter 9

## Heat Maps

Temporal patterns can show at what time certain devices are exposed to how much load. Heatmaps show quantitative values based on two axes. These can be day and hours, month and day, etc. The cell at the intersection contains the corresponding value. Depending on the context, this can be an average value, a maximum/minimum value, etc. This representation allows the viewer to see short-term patterns and long-term trends in the data with a higher temporal granularity.

This chapter shows different types of heat maps which are useful for energy data analysis and pattern recognition.

## 9.1 Calendar

### 9.1.1 Goal

Create a calendar heat map with daily energy consumption values.

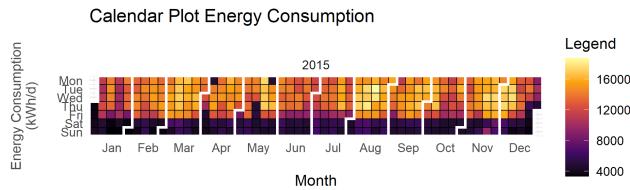


Figure 9.1: Calendar Heat Map

### 9.1.2 Data Basis

Daily energy consumption values of one whole year in an interval of 15mins.

### 9.1.3 Solution

Create a new script, copy/paste the following code and run it:

```
library(ggplot2)
library(ggTimeSeries)
library(plotly)
library(lubridate)
library(dplyr)
library(tidyquant)

data <- readRDS(system.file("sampleData/eboBookEleMeter.rds", package = "redutils"))

data <- data[-nrow(data),]

data$timestamp <- parse_date_time(data$timestamp,
                                    order = "YmdHMS",
                                    tz = "UTC")
```

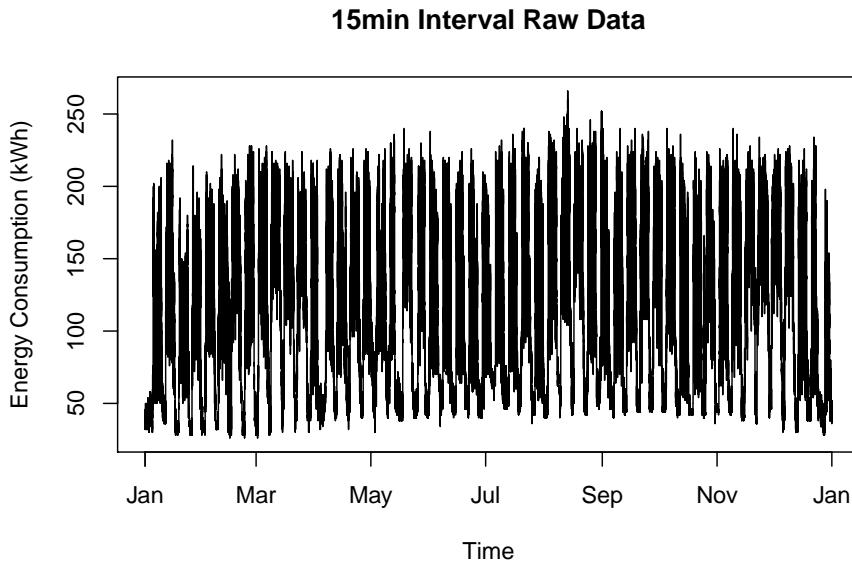


Figure 9.2: Raw Data for Decomposition Plot Short Term

```

data$day <- as.Date(lubridate::floor_date(data$timestamp, "day"))

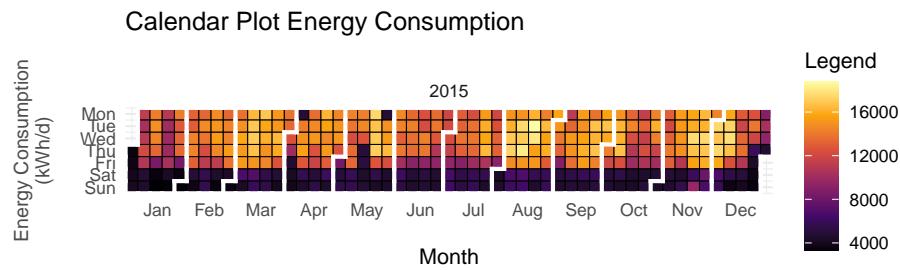
data <- data %>%
  select(-timestamp)

data.plot <- data %>%
  dplyr::group_by(day) %>%
  dplyr::mutate(calcVal = sum(value, na.rm = TRUE)) %>%
  ungroup() %>%
  select(-value) %>%
  unique()

plot <- ggplot_calendar_heatmap(data.plot,
                                   "day",
                                   "calcVal",
                                   monthBorderStyle = 1,
                                   monthBorderColour = "white",
                                   monthBorderLineEnd = "square") +
  scale_fill_viridis_c(option = "B") +
  theme_minimal() +
  theme(axis.title.y = element_text(colour = "grey30", size = 10, face = "plain"),
        )+
  labs(x = "\nMonth",
       y = "Energy Consumption\n(kWh/d)\n ",
       fill = "Legend") +
  facet_wrap(~Year, ncol = 1) +
  ggtitle("Calendar Plot Energy Consumption\n")

```

```
plot
```



```
# create the interactive plot (optional, uncomment line)
#ggplotly(plot)
```

```
# save static plot as png (optional)
ggsave("images/plotHeatMapCalendar.png", plot)
```

#### 9.1.4 Discussion

Some findings:

- first two days in year minimal consumption
- 6th of April: Easter Monday
- 25th of May: Whitmonday (de: Pfingstmontag)
- More usage in August
- In November one Sunday with unusual high consumption
- On Fridays in general less consumption

## 9.2 Median-Weeks

### 9.2.1 Goal

Create an energy consumption heat map of a typical weeks depending on the season of the year.

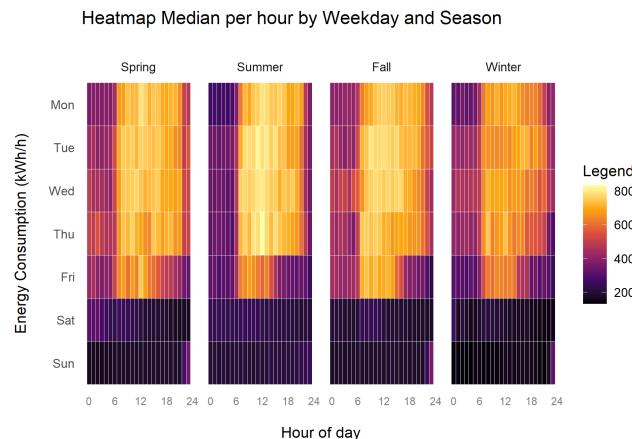


Figure 9.3: Heat Map of Median Weeks per Season of Year

### 9.2.2 Data Basis

Daily energy consumption values of one whole year in an interval of 15mins.

### 9.2.3 Solution

Create a new script, copy/paste the following code and run it:

```
library(redutils)
library(plotly)

data <- readRDS(system.file("sampleData/eboBookEleMeter.rds", package = "redutils"))
plot <- plotHeatmapMedianWeeks(data, locTimeZone = "Europe/Zurich")

# show the static plot
plot
```

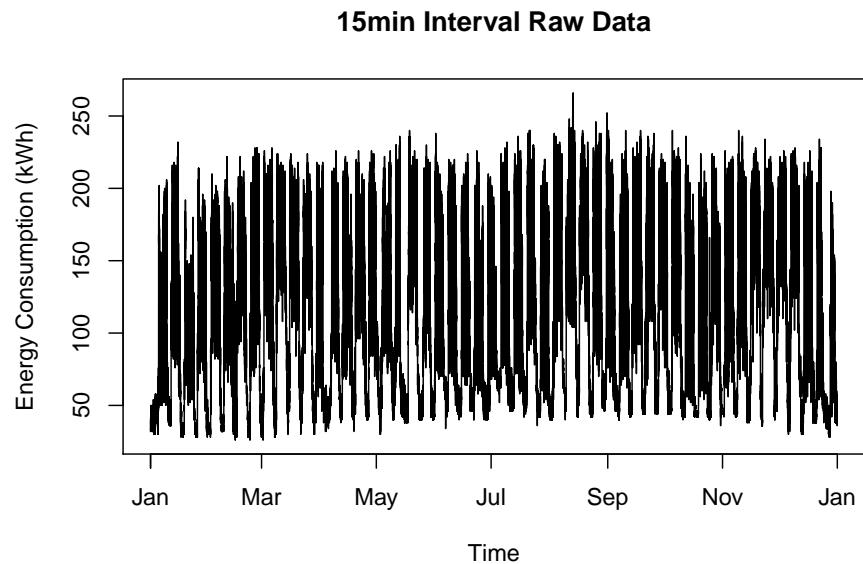
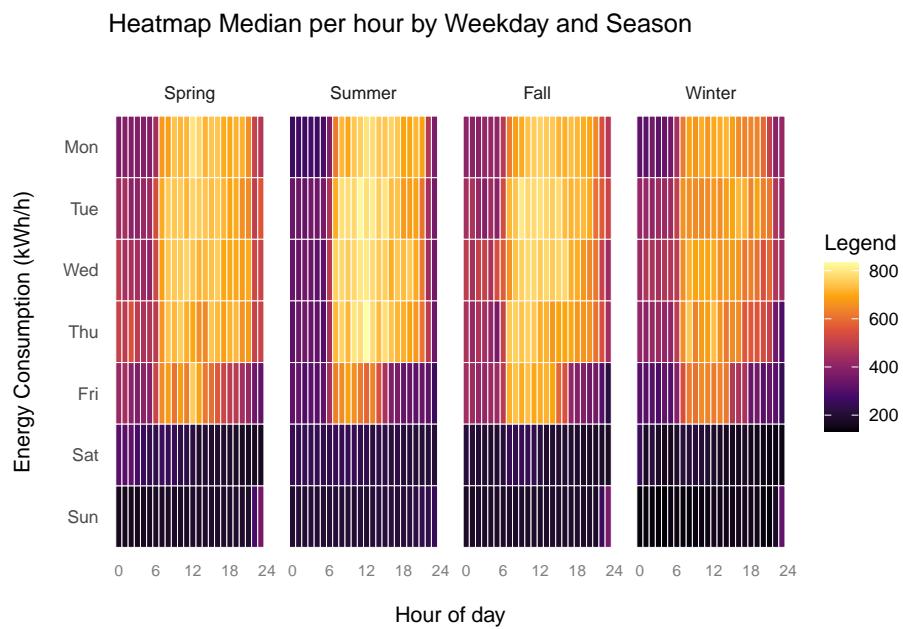


Figure 9.4: Raw Data for Decomposition Plot Short Term



```
# create the interactive plot (optional, uncomment line)
#ggplotly(plot)

# save static plot as png (optional)
ggsave("images/plotHeatMapMedianWeeks.png", plot)
```

#### 9.2.4 Discussion

Some findings:

- Increased consumption at midnight, but not visible in Summer, probably heating affected
- Clearly less consumption at weekends, starting already friday afternoon
- High peaks on Tuesdays and Thursdays in summer



## Chapter 10

# Typical Daily Profiles

An important step in energy data analysis is the recognition of patterns. For this purpose, the data are first aggregated to hourly values, averaged and displayed as typical daily patterns. The daily profiles can be displayed separately for the weekdays and the seasons.

This chapter shows some useful visualizations to accommodate this recognition.

## 10.1 Overview

### 10.1.1 Goal

Create an overview of typical daily profiles per weekday and season of year with a confidence band where most of the values lie.

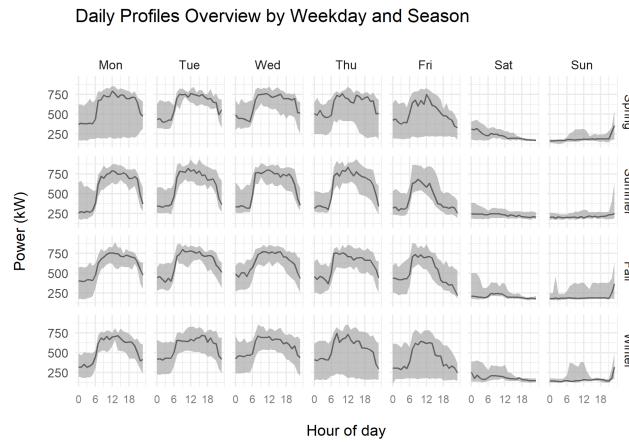


Figure 10.1: Overview of Daily Profiles by Weekday and Season

### 10.1.2 Data Basis

Energy consumption values of one whole year in an interval of 15mins.

### 10.1.3 Solution

Create a new script, copy/paste the following code and run it:

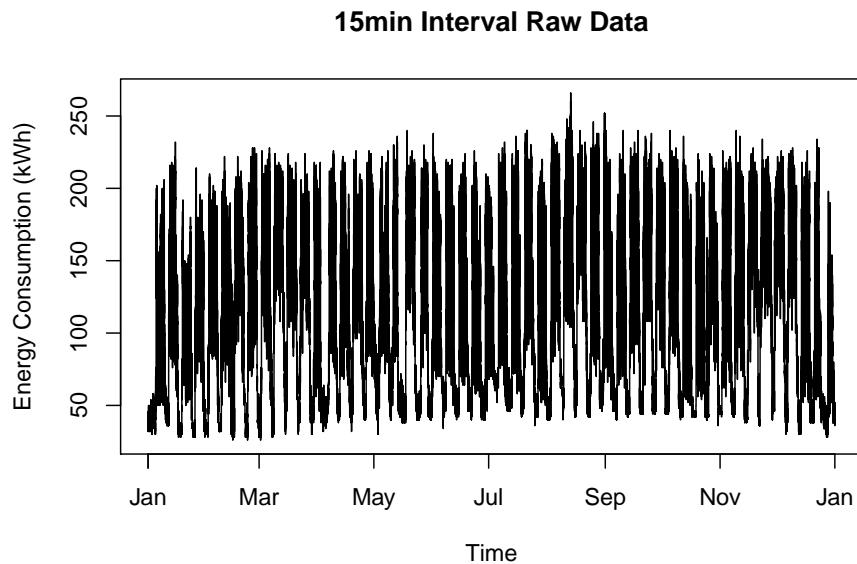
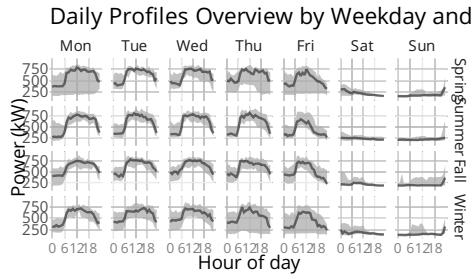


Figure 10.2: Raw Data for Decomposition Plot Short Term

```
    col = "black",
confidence = 95.0)

ggplotly(plot)
```



```
# save static plot as png (optional)
ggsave("images/plotDailyProfOverview.png", plot)
```

## 10.2 Overlayed

### 10.2.1 Goal

Create a plot of all data per week by season of the year.

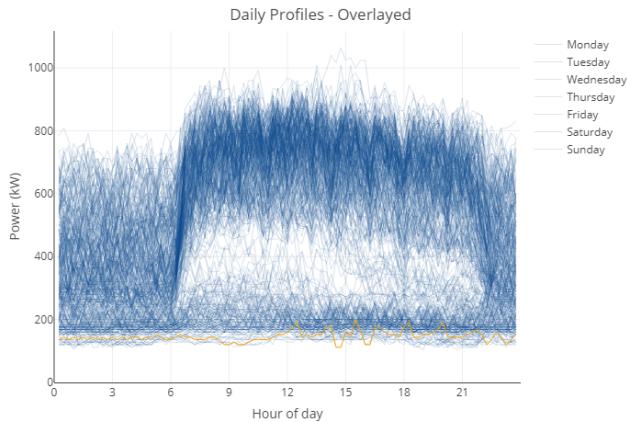


Figure 10.3: Overlayed Daily Profiles

### 10.2.2 Data Basis

Energy consumption values of one whole year in an interval of 15mins.

### 10.2.3 Solution

Create a new script, copy/paste the following code and run it:

```
# change language to English, otherwise weekdays are in local language
Sys.setlocale("LC_TIME", "English")

## [1] "English_United States.1252"

library(plotly)
library(dplyr)
library(lubridate)

# load time series data
df <- readRDS(system.file("sampleData/eboBookEleMeter.rds", package = "reductools"))
df <- mutate(df, value = value * 4)

# add metadata for later grouping and visualization purposes
df$x <- hour(df$timestamp) + minute(df$timestamp)/60 + second(df$timestamp) / 3600
```

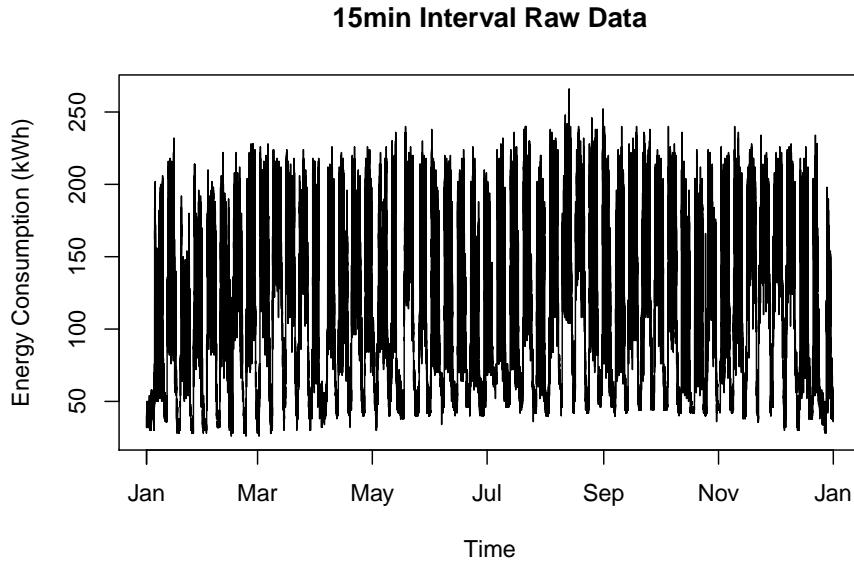


Figure 10.4: Raw Data for Decomposition Plot Short Term

```

df$weekday <- weekdays(df$timestamp)
df$weekday <- factor(df$weekday, c("Monday", "Tuesday", "Wednesday", "Thursday", "Friday", "Saturday", "Sunday"))
df$day <- as.Date(df$timestamp, format = "%Y-%m-%d %H:%M:%S")

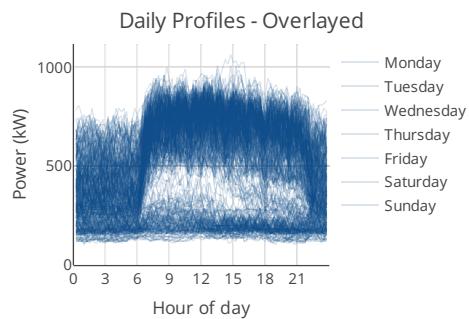
df <- df %>% mutate(value = ifelse(x == 0.00, NA, df$value))

# plot graph with all time series
rangeX <- seq(0, 24, 0.25)
maxValue <- max(df$value, na.rm = TRUE)*1.05

df %>%
  highlight_key(~day) %>%
  plot_ly(x=~x,
          y=~value,
          color=~weekday,
          type="scatter",
          mode="lines",
          line = list(width = 1),
          alpha = 0.15,
          colors = "dodgerblue4",
          text = ~day,
          hovertemplate = paste("Time: ", format(df$timestamp, "%H:%M"),
                                "<br>Date: ", format(df$timestamp, "%Y-%m-%d"),
                                "<br>Value: %{y:.0f}")) %>%
# workaround with add_trace to have fixed y axis when selecting a dedicated day
add_trace(x = 0, y = 0, type = "scatter", showlegend = FALSE, opacity=0) %>%
add_trace(x = 24, y = maxValue, type = "scatter", showlegend = FALSE, opacity=0) %>

```

```
layout(title = "Daily Profiles - Overlaid",
      showlegend = TRUE,
      xaxis = list(
        title = "Hour of day",
        range = rangeX,
        tickvals = list(0, 3, 6, 9, 12, 15, 18, 21),
        showline=TRUE
      ),
      yaxis = list(
        title = "Power (kW)",
        range = c(0, maxValue)
      )
    ) %>%
highlight(on = "plotly_hover",
          off = "plotly_doubleclick",
          color = "orange",
          opacityDim = 1.0,
          selected = attrs_selected(showlegend = FALSE)) %>% # this hides elements in the legend
plotly::config(modeBarButtons = list(list("toImage")), displaylogo = FALSE)
```



## 10.3 Mean

### 10.3.1 Goal

Create a plot of mean data per week.

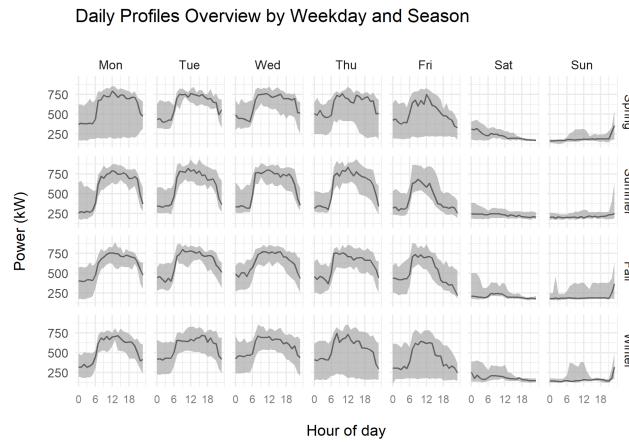


Figure 10.5: Mean Daily Profiles per Weekday

### 10.3.2 Data Basis

Energy consumption values of one whole year in an interval of 15mins.

### 10.3.3 Solution

Create a new script, copy/paste the following code and run it:

```
# change language to English, otherwise weekdays are in local language
Sys.setlocale("LC_TIME", "English")

## [1] "English_United States.1252"

library(plotly)
library(dplyr)
library(lubridate)

# load time series data
df <- readRDS(system.file("sampleData/eboBookEleMeter.rds", package = "redutils"))
df <- mutate(df, value = value * 4)

# add metadata for later grouping and visualization purposes
```

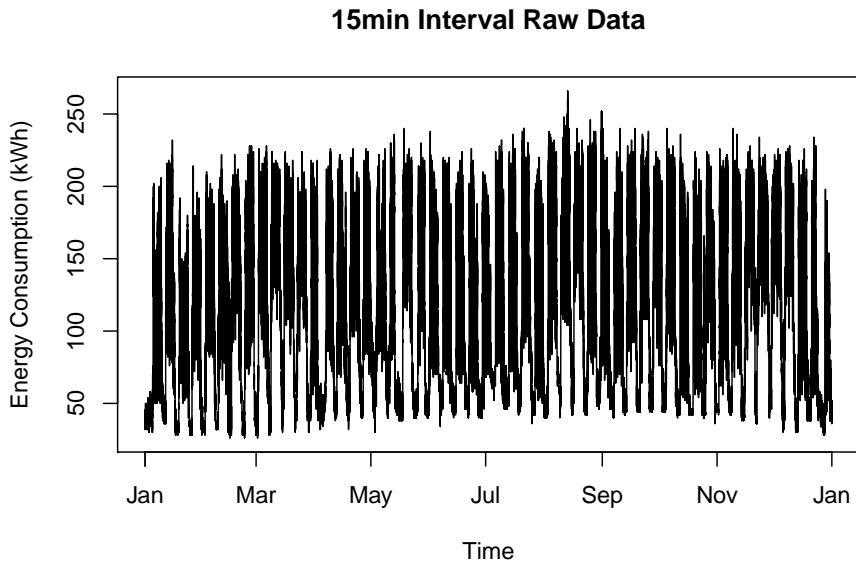


Figure 10.6: Raw Data for Decomposition Plot Short Term

```

df$x <- hour(df$timestamp) + minute(df$timestamp)/60 + second(df$timestamp) / 3600
df$weekday <- weekdays(df$timestamp)
df$weekday <- factor(df$weekday, c("Monday", "Tuesday", "Wednesday", "Thursday", "Friday", "Saturday", "Sunday"))

df <- df %>% dplyr::mutate(value = ifelse(x == 0.00, NA, df$value))

# Calculate Mean value for all 15 minutes for each weekday
df <- df %>% group_by(weekday, x) %>% dplyr::mutate(dayTimeMean = mean(value)) %>% ungroup()

# shrink data frame
df <- df %>%
  select(x, weekday, timestamp, dayTimeMean) %>%
  unique() %>%
  na.omit() %>%
  arrange(weekday, x)

# plot graph with mean values
maxValMean <- max(df$dayTimeMean, na.rm = TRUE)*1.05

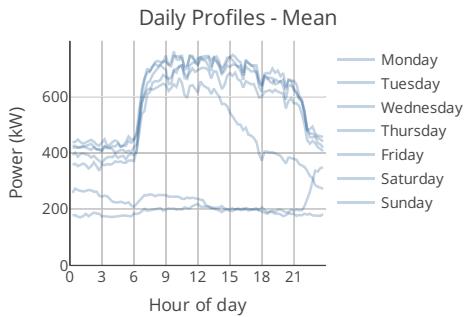
df %>%
  highlight_key(~weekday) %>%
  plot_ly(x=-x,
          y=~dayTimeMean,
          color=~weekday,
          type="scatter",
          mode="lines",
          alpha = 0.25,

```

```

colors = "dodgerblue4",
text = ~weekday,
hovertemplate = paste("Time: ", format(df$timestamp, "%H:%M"),
                      "<br>Mean: %{y:.0f}")) %>%
# workaround with add_trace to have fixed y axis when selecting a dedicated day
add_trace(x = 0, y = 0, type = "scatter", showlegend = FALSE, opacity=0) %>%
add_trace(x = 24, y = maxValMean, type = "scatter", showlegend = FALSE, opacity=0) %>%
layout(title = "Daily Profiles - Mean",
       showlegend = TRUE,
       xaxis = list(
         title = "Hour of day",
         tickvals = list(0, 3, 6, 9, 12, 15, 18, 21)
       ),
       yaxis = list(
         title = "Power (kW)",
         range = c(0, maxValMean)
       )
) %>%
highlight(on = "plotly_hover",
           off = "plotly_doubleclick",
           color = "orange",
           opacityDim = 0.7,
           selected = attrs_selected(showlegend = FALSE)) %>% # this hides elements in the legend
plotly::config(modeBarButtons = list(list("toImage")), displaylogo = FALSE)

```



```

# save static plot as png (optional)
ggsave("images/plotDailyProfMean.png", plot)

```

## 10.4 Decomposed

### 10.4.1 Goal

Create a plot of detrended mean data per week as recommended in “Building electricity consumption: Data analytics of building operations with classical time series decomposition and case based subsetting”, Pickering et al, 2018

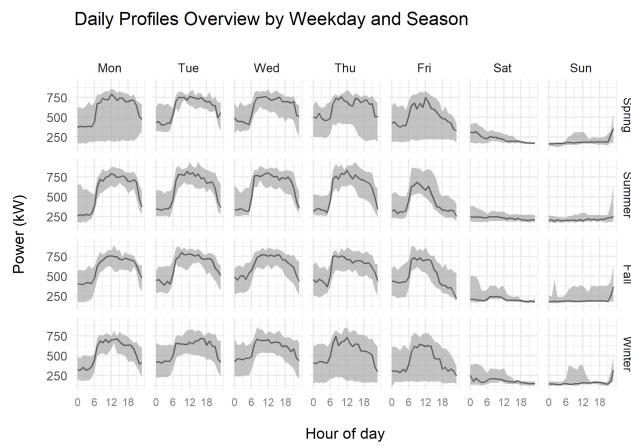


Figure 10.7: Mean Daily Profiles per Weekday

### 10.4.2 Data Basis

Energy consumption values of one whole year in an interval of 15mins.

### 10.4.3 Solution

Create a new script, copy/paste the following code and run it:

```
library(plotly)
library(redutils)

# load time series data
df <- readRDS(system.file("sampleData/eboBookEleMeter.rds", package = "redutils"))
df <- mutate(df, value = value * 4)

p <- plotDailyProfilesDecomposed(df, locTimeZone = "Europe/Zurich")
ggplotly(p)
```

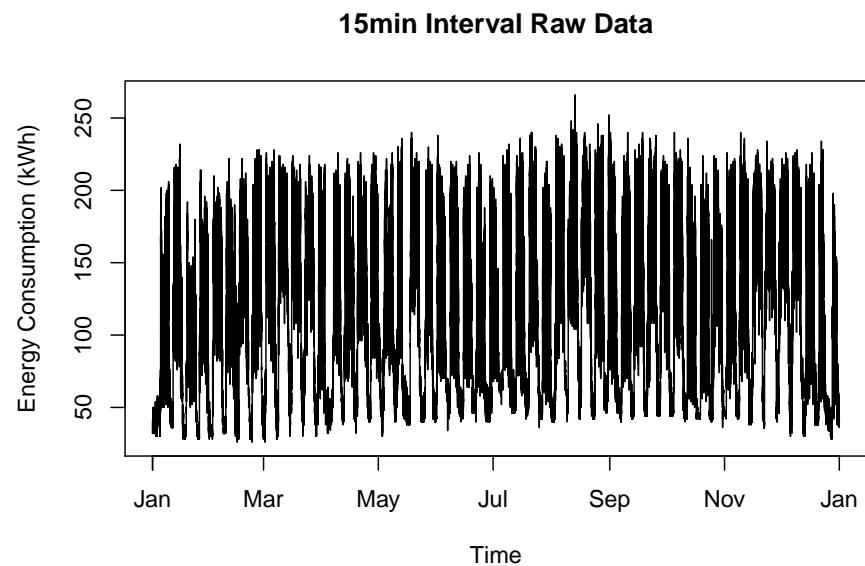
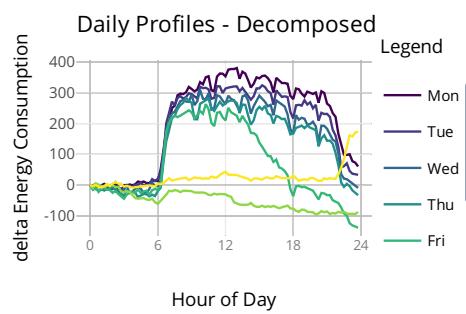


Figure 10.8: Raw Data for Decomposition Plot Short Term



```
# save static plot as png (optional)
ggsave("images/plotDailyProfDecomposed.png", plot)
```



# **Chapter 11**

## **Comfort Plots**

Satisfied and healthy residents are important, thus an energetic optimization should not influence the comfort if possible. The recipes in this chapter focus on some typical comfort related visualizations which help identifying multiple problems like moisture and damage of wooden floor because of the humidity influence.

This chapter shows how to create some popular comfort plots.

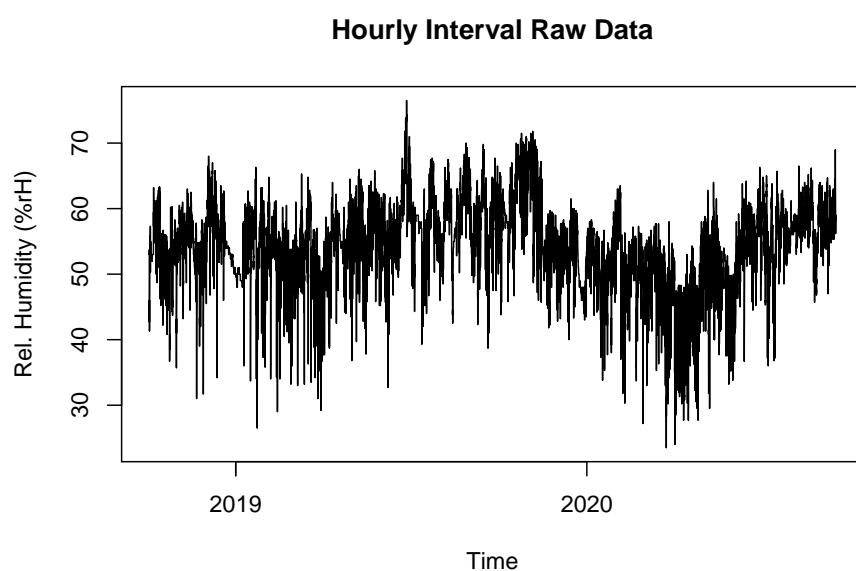
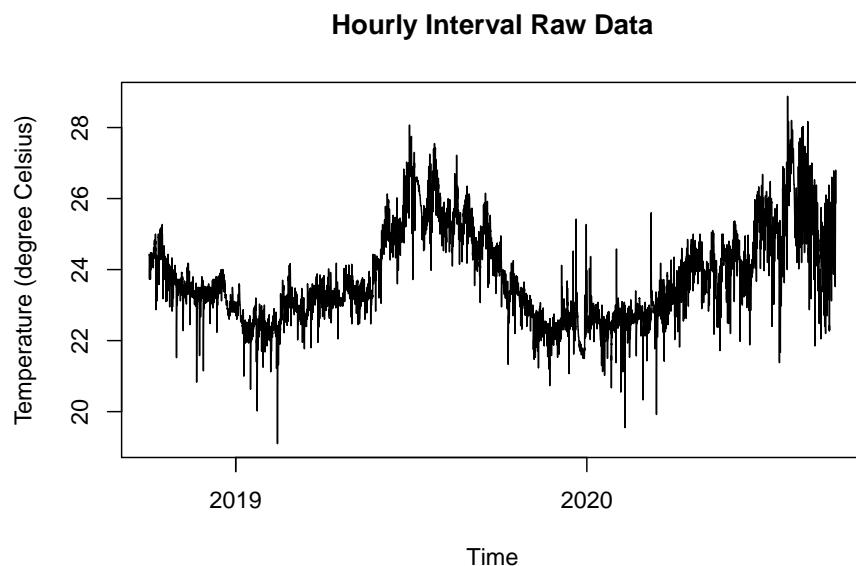
## 11.1 Mollier hx Diagram

### 11.1.1 Goal

You want to plot a mollier h-x diagram:

Figure 11.1: Mollier hx Diagram with comfort zone

### 11.1.2 Data Basis



### 11.1.3 Solution

The sensor data is not in a constant intervall and not yet aggregated. So after reading in the time series the data has to get filtered and aggregated per day.

Finally use the plot function `mollierHxDiagram` from the `reduutils` package (R Energy Data Utilities). If you have not yet installed this package, proceed as follows:

```
install.packages("devtools")
library(devtools)
install_github("hslu-ige-laes/reduutils")
```

Create a new script, copy/paste the following code and run it:

```
library(reduutils)
library(dplyr)
library(lubridate)

# read and print data
data <- read.csv("https://github.com/hslu-ige-laes/edar/raw/master/sampleData/flatTempHum.csv",
                 stringsAsFactors=FALSE,
                 sep =";")

# select temperature and humidity and remove empty cells
data <- data %>% select(time, FlatA_Temp, FlatA_Hum) %>% na.omit()

# create column with day for later grouping
data$time <- parse_date_time(data$time, "YmdHMS", tz = "Europe/Zurich")
data$day <- as.Date(cut(data$time, breaks = "day"))

# calculate daily mean of temperature and humidity
data <- data %>%
  group_by(day) %>%
  mutate(tempMean = mean(as.numeric(FlatA_Temp)),
        humMean = mean(as.numeric(FlatA_Hum)))
  ) %>%
ungroup()

# shrink down to daily values and remove rows with empty values
data <- data %>% select(day, tempMean, humMean) %>% unique() %>% na.omit()

# plot mollier hx diagram
plot <- plotMollierHx(data)

plot
```

```
# save static plot as png (optional)
library(r2d3)
save_d3_png(plot, "images/comfortMollierHx.png")
```

## 11.2 SIA 180 Thermal Comfort

### 11.2.1 Goal

You want to plot a diagram like the one from the SIA 180:2014

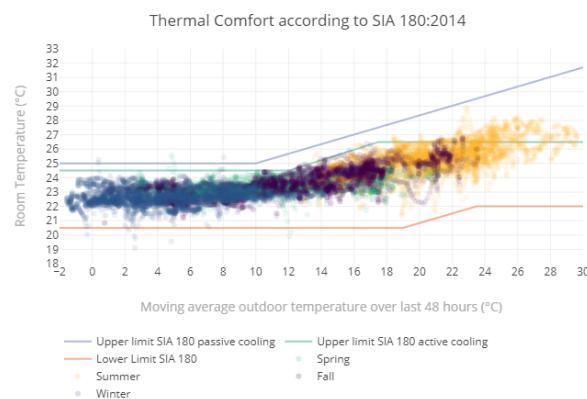
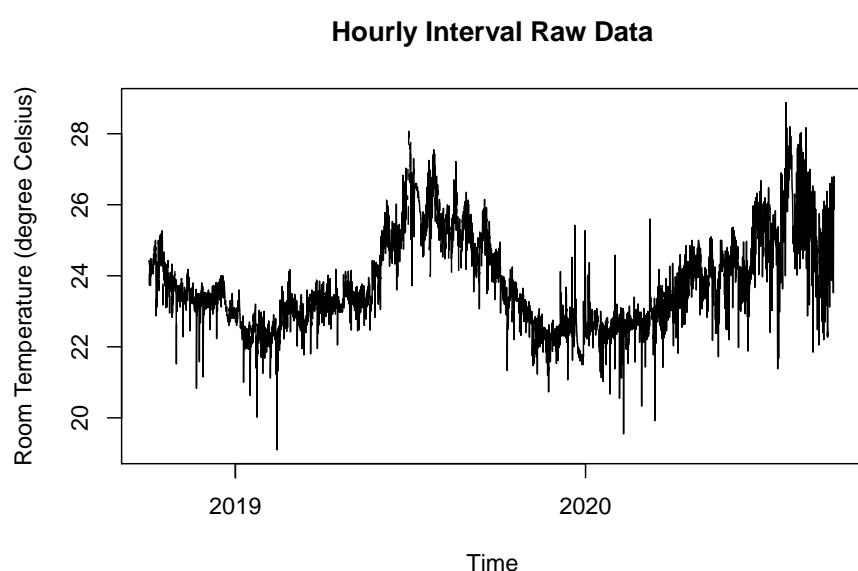
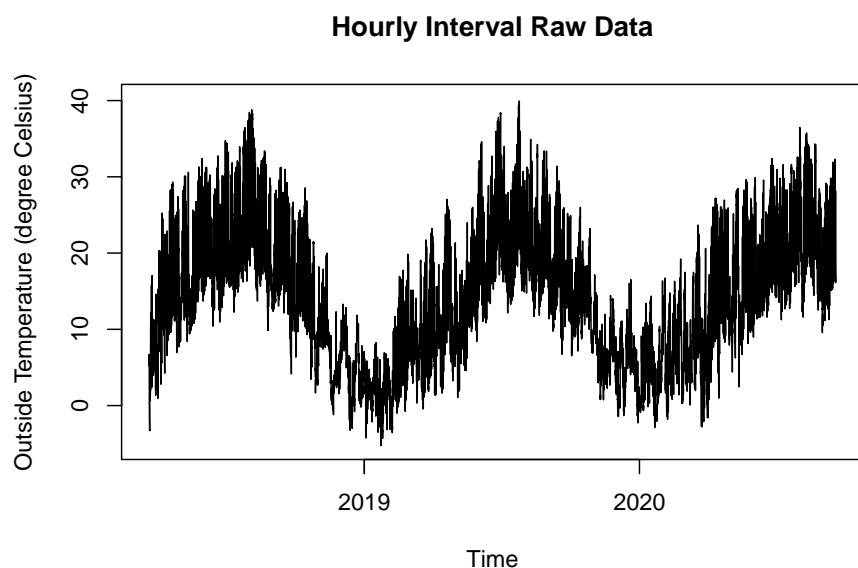


Figure 11.2: Thermal Comfort according to SIA 180:2014

### 11.2.2 Data Basis



### 11.2.3 Solution

Create a new script, copy/paste the following code and run it:

```

library(reddutils)
library(dplyr)
library(lubridate)
library(zoo)
library(plotly)

# load time series data and aggregate mean values
dfTemp0a <- read.csv("https://github.com/hslu-ige-laes/edar/raw/master/sampleData/centralOutsideTemp.csv",
                      stringsAsFactors=FALSE,
                      sep =";")

dfTemp0a$time <- parse_date_time(dfTemp0a$time,
                                    order = "YmdHMS",
                                    tz = "UTC")

dfTemp0a$hour <- cut(dfTemp0a$time, breaks = "hour")

dfTemp0a <- dfTemp0a %>%
  group_by(hour) %>%
  mutate(tempMean = mean(centralOutsideTemp)) %>%
  ungroup() %>%
  select(time, tempMean) %>%
  unique()

# Fill missing values with NA
grid.df <- data.frame(time = seq(min(dfTemp0a$time, na.rm = TRUE),
                                   max(dfTemp0a$time, na.rm = TRUE),
                                   by = "hour"))
dfTemp0a <- merge(dfTemp0a, grid.df, all = TRUE)

dfTemp0a <- dfTemp0a %>%
  mutate(temp0a = rollmean(tempMean, 48, fill = NA, align = "right"))

dfTemp0a <- dfTemp0a %>%
  select(time, temp0a) %>%
  unique() %>%
  na.omit()

dfTempR <- read.csv("https://github.com/hslu-ige-laes/edar/raw/master/sampleData/flatTempHum.csv",
                     stringsAsFactors=FALSE,
                     sep =";")

dfTempR$time <- parse_date_time(dfTempR$time,
                                 order = "YmdHMS",
                                 tz = "UTC")

# select temperature and humidity and remove empty cells
dfTempR <- dfTempR %>% select(time, FlatA_Temp) %>% na.omit()

dfTempR$hour <- cut(dfTempR$time, breaks = "hour")

dfTempR <- dfTempR %>%

```

```

group_by(hour) %>%
  mutate(tempR = mean(FlatA_Temp)) %>%
  ungroup() %>%
  select(time, tempR) %>%
  unique()

# Fill missing values with NA
grid.df <- data.frame(time = seq(min(dfTempR$time, na.rm = TRUE),
                                  max(dfTempR$time, na.rm = TRUE),
                                  by = "hour"))
dfTempR <- merge(dfTempR, grid.df, all = TRUE)

data <- merge(dfTempR, dfTemp0a, all = TRUE) %>% unique() %>% na.omit()

data$season <- reldutils::getSeason(data$time)

# plot diagram

# axis properties
minx <- floor(min(0, min(data$temp0a)))
maxx <- ceiling(max(28, max(data$temp0a)))

miny <- floor(min(21.0,min(data$tempR))-1)
maxy <- ceiling(max(32.0,max(data$tempR))+1)

# line setpoint heat
df.heatSp <- data.frame(temp0a = c(minx, 19, 23.5, maxx), tempR = c(20.5, 20.5, 22, 22))

# line setpoint cool according to SIA 180:2014 Fig. 4
df.coolSp1 <- data.frame(temp0a = c(minx, 12, 17.5, maxx),tempR = c(24.5, 24.5, 26.5, 26.5))

# line setpoint cool according to SIA 180:2014 Fig. 3
df.coolSp2 <- data.frame(temp0a = c(minx, 10, maxx),tempR = c(25, 25, 0.33 * maxx + 21.8))

data %>%
  plot_ly(showlegend = TRUE) %>%
  add_lines(data = df.coolSp2,
            x = ~temp0a,
            y = ~tempR,
            name = "Upper limit SIA 180 passive cooling",
            opacity = 0.7,
            color = "#FDE725FF",
            hoverinfo = "text",
            text = ~ paste("Upper limit SIA 180 passive cooling",
                           "<br />TempR: ", sprintf("%.1f \u00b0C", tempR),
                           "<br />Temp0a: ", sprintf("%.1f \u00b0C", temp0a)
            )
  ) %>%
  add_lines(data = df.coolSp1,
            x = ~temp0a,
            y = ~tempR,
            name = "Upper limit SIA 180 active cooling",
            opacity = 0.7,
            color = "#1E9B8AFF",
            hoverinfo = "text",
            text = ~ paste("Upper limit SIA 180 active cooling",
                           "<br />TempR: ", sprintf("%.1f \u00b0C", tempR),
                           "<br />Temp0a: ", sprintf("%.1f \u00b0C", temp0a)
            )
  )

```

```

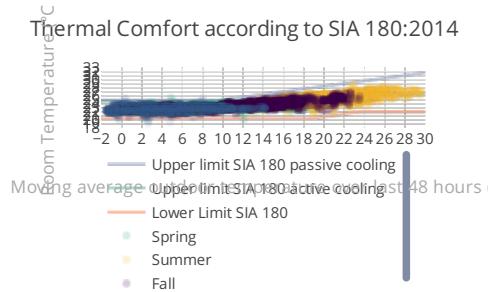
) %>%
add_lines(data = df.heatSp,
  x = ~temp0a,
  y = ~tempR,
  name = "Lower Limit SIA 180",
  opacity = 0.7,
  color = "#440154FF",
  hoverinfo = "text",
  text = ~ paste("Lower Limit SIA 180",
                 "<br />TempR: ", sprintf("%.1f \u000B0C", tempR),
                 "<br />Temp0a: ", sprintf("%.1f \u000B0C", temp0a)
  )
) %>%
add_markers(data = data %>% filter(season == "Spring"),
  x = ~temp0a,
  y = ~tempR,
  name = "Spring",
  marker = list(color = "#2db27d", opacity = 0.1),
  hoverinfo = "text",
  text = ~ paste("TempR: ", sprintf("%.1f \u000B0C", tempR),
                 "<br />Temp0a: ", sprintf("%.1f \u000B0C", temp0a),
                 "<br />Date:      ", time,
                 "<br />Season:   ", season
  )
) %>%
add_markers(data = data %>% filter(season == "Summer"),
  x = ~temp0a,
  y = ~tempR,
  name = "Summer",
  marker = list(color = "#febc2b", opacity = 0.1),
  hoverinfo = "text",
  text = ~ paste("TempR: ", sprintf("%.1f \u000B0C", tempR),
                 "<br />Temp0a: ", sprintf("%.1f \u000B0C", temp0a),
                 "<br />Date:      ", time,
                 "<br />Season:   ", season
  )
) %>%
add_markers(data = data %>% filter(season == "Fall"),
  x = ~temp0a,
  y = ~tempR,
  name = "Fall",
  marker = list(color = "#440154", opacity = 0.1),
  hoverinfo = "text",
  text = ~ paste("TempR: ", sprintf("%.1f \u000B0C", tempR),
                 "<br />Temp0a: ", sprintf("%.1f \u000B0C", temp0a),
                 "<br />Date:      ", time,
                 "<br />Season:   ", season
  )
) %>%
add_markers(data = data %>% filter(season == "Winter"),
  x = ~temp0a,
  y = ~tempR,
  name = "Winter",
  marker = list(color = "#365c8d", opacity = 0.1),
  hoverinfo = "text",
  text = ~ paste("TempR: ", sprintf("%.1f \u000B0C", tempR),
                 "<br />Temp0a: ", sprintf("%.1f \u000B0C", temp0a),

```

```

        "<br />Date:      ", time,
        "<br />Season:   ", season
    )
) %>%
layout(
  title = "Thermal Comfort according to SIA 180:2014",
  xaxis = list(title = "Moving average outdoor temperature over last 48 hours (\u00b0C)",
               range = c(minx, maxx),
               zeroline = FALSE,
               tick0 = minx,
               dtick = 2,
               titlefont = list(size = 14, color = "darkgrey")),
  yaxis = list(title = "Room Temperature (\u00b0C)",
               range = c(miny, maxy),
               dtick = 1,
               titlefont = list(size = 14, color = "darkgrey")),
  hoverlabel = list(align = "left"),
  margin = list(l = 80, t = 50, r = 50, b = 10),
  legend = list(orientation = 'h',
                x = 0.0,
                y = -0.3)
) %>%
plotly::config(modeBarButtons = list(list("toImage")),
               displaylogo = FALSE,
               toImageButtonOptions = list(
                 format = "png"
               )
)
)

```





## **Chapter 12**

# **Miscellaneous**

Finally, some visualizations that did not fit into any of the above chapters and are not (yet) worth a separate chapter. But these are not less interesting...

## 12.1 Electricity Household

### 12.1.1 Goal

You want to plot an electricity consumption diagram with:

- upper plot with daily energy consumption in kWh/day
- lower plot with standby-losses in Watts

Additionaly we would like to see the consumption of an average Swiss household.

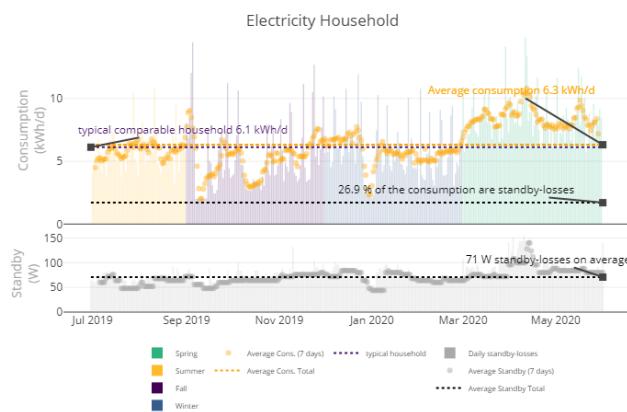


Figure 12.1: Plot Electricity Household

### 12.1.2 Data Basis

- A csv file with time series of an electric meter in 15 minute interval.

### 12.1.3 Solution

Create a new script, copy/paste the following code and run it:

```
library(reudutils)
library(dplyr)
library(lubridate)
library(zoo)
library(plotly)

# load time series data and aggregate mean values
df <- read.csv("https://github.com/hslu-ige-laes/edar/raw/master/sampleData/flatElectricity.csv",
```

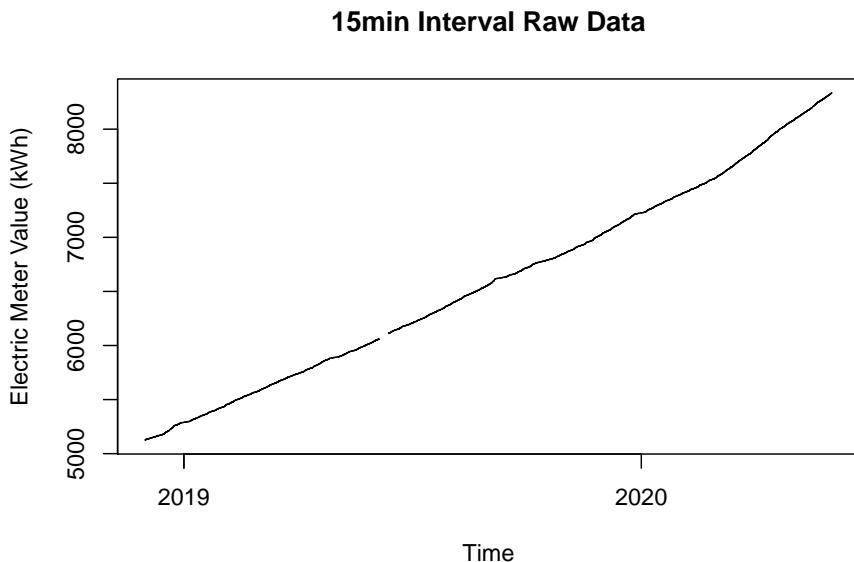


Figure 12.2: Raw Data for Electricity Household Plot

```

stringsAsFactors=FALSE,
sep =";")

df$time <- parse_date_time(df$time,
                           order = "YmdHMS",
                           tz = "UTC")

# select room
df <- df %>% select(time, FlatC_Ele)

# rename columns
colnames(df) <- c("timestamp", "meterValue")

# filter timerange
df <- df %>% filter(timestamp > "2019-07-01")

# Fill missing values with NA
grid.df <- data.frame(timestamp = seq(min(df$timestamp, na.rm = TRUE),
                                         max(df$timestamp, na.rm = TRUE),
                                         by = "15 mins"))
df <- merge(df, grid.df, all = TRUE)

# convert steadily counting energy meter value from kWh to power in kW
df <- df %>%
  mutate(value = (meterValue - lag(meterValue))) %>%
  select(-meterValue)

```

```

# remove negative values which occur because of change summer/winter time
df <- df %>% filter(value >= 0)

# determine date related parameters for later filtering
df$day <- as.Date(df$time, tz = "UTC")
df$week <- lubridate::week(df$time)
df$month <- lubridate::month(df$time)
df$year <- lubridate::year(df$time)

# data cleansing
# tag NA
df <- df %>% mutate(deleteNA = ifelse(is.na(value), 1, 0))

# tag values below 0 and higher than 9.2 kW
df <- df %>% mutate(deleteHiLoVal = ifelse(value > 9.2, 1, ifelse(value < 0, 1, 0)))
# Assumption max. fuse 40 ampere (higher fuses for single family houses)
# this results in continuous power 9.2 kW
# this results in an hourly consumption of 9.2kWh
# over 24h = approx. 221 kWh max. consumption per day

# tag whole days which have one or more values to delete, keep only whole valid days
df <- df %>%
  group_by(day) %>%
  mutate(delete = sum(deleteNA, na.rm = TRUE) + sum(deleteHiLoVal, na.rm = TRUE))

df <- df %>% ungroup()

# delete full days with invalid data
df <- df %>%
  filter(delete == 0) %>%
  select(-deleteNA, -deleteHiLoVal, -delete)

# determine season for later filtering
df <- df %>% mutate(season = redutils::getSeason(timestamp))

# calculate sum and min per day
df <- df %>% dplyr::group_by(day) %>% dplyr::mutate(sum = sum(value))
df <- df %>% dplyr::group_by(day) %>% dplyr::mutate(min = min(value)*1000*4)
df <- df %>% ungroup()

df <- df %>% dplyr::select(day, sum, min, season) %>% unique()

df <- df %>% dplyr::mutate(ravgUsage = zoo::rollmean(x=sum, 7, fill = NA))
df <- df %>% dplyr::mutate(rminStandby = -1 * zoo::rollmaxr(x = -1 * min, 7, fill = NA))

typEleConsVal <- redutils::getTypEleConsHousehold(occupants = 2, rooms = 3.5, bldgType = "multi", laundry = 0)

# Plot
main = "Electricity consumption private household"
minY <- 0
maxYUsage <- max(df %>% select(sum), na.rm=TRUE)
maxYUsage <- max(maxYUsage, typEleConsVal/365)
maxYStandby <- max(max(df %>% select(min), na.rm=TRUE), 0.25*maxYUsage/24*1000)
minX <- min(df$day)
maxX <- max(df$day)
averageUsage <- mean(df$sum, na.rm=TRUE)

```

```

averageStandby <- mean(df$rminStandby, na.rm=TRUE)
shareStandby <- nrow(df %>% select(sum) %>% na.omit()) * averageStandby * 24 / (1000 * sum(df$sum, na.rm=TRUE)) * 100

# legend
l <- list(
  orientation = "h",
  tracegroupgap = "20",
  font = list(size = 8),
  xanchor = "center",
  x = 0.5,
  itemclick = FALSE
)

fig1 <- df %>%
  plot_ly(x = ~day, showlegend = TRUE) %>%
  add_trace(data = df %>% filter(season == "Spring"),
            type = "bar",
            y = ~sum,
            name = "Spring",
            legendgroup = "group1",
            marker = list(color = "#2db27d", opacity = 0.2),
            hoverinfo = "text",
            text = ~ paste("<br />daily usage:      ", sprintf("%.1f kWh/d", sum),
                          "<br />rolling average:    ", sprintf("%.1f kWh/d", ravgUsage),
                          "<br />Average vis. points: ", sprintf("%.1f kWh/d", averageUsage),
                          "<br />Date:                  ", day,
                          "<br />Season:                ", season
            )
  ) %>%
  add_trace(data = df %>% filter(season == "Summer"),
            type = "bar",
            y = ~sum,
            name = "Summer",
            legendgroup = "group1",
            marker = list(color = "#febc2b", opacity = 0.2),
            hoverinfo = "text",
            text = ~ paste("<br />rolling average:      ", sprintf("%.1f kWh/d", ravgUsage),
                          "<br />Average vis. points: ", sprintf("%.1f kWh/d", averageUsage),
                          "<br />Date:                  ", day,
                          "<br />Season:                ", season
            )
  ) %>%
  add_trace(data = df %>% filter(season == "Fall"),
            type = "bar",
            y = ~sum,
            name = "Fall",
            legendgroup = "group1",
            marker = list(color = "#440154", opacity = 0.2),
            hoverinfo = "text",
            text = ~ paste("<br />rolling average:      ", sprintf("%.1f kWh/d", ravgUsage),
                          "<br />Average vis. points: ", sprintf("%.1f kWh/d", averageUsage),
                          "<br />Date:                  ", day,
                          "<br />Season:                ", season
            )
  ) %>%
  add_trace(data = df %>% filter(season == "Winter"),
            type = "bar",

```

```

y = ~sum,
name = "Winter",
legendgroup = "group1",
marker = list(color = "#365c8d", opacity = 0.2),
hoverinfo = "text",
text = ~ paste("<br />rolling average:      ", sprintf("%.1f kWh/d", ravgUsage),
              "<br />Average vis. points: ", sprintf("%.1f kWh/d", averageUsage),
              "<br />Date:                  ", day,
              "<br />Season:                ", season
            )
)
) %>
add_trace(data = df,
           type = "scatter",
           mode = "markers",
           y = ~ravgUsage,
           name = "Average Cons. (7 days)",
           legendgroup = "group2",
           marker = list(color = "orange", opacity = 0.4, symbol = "circle"),
           hoverinfo = "text",
           text = ~ paste("<br />rolling average:      ", sprintf("%.1f kWh/d", ravgUsage),
                         "<br />Average vis. points: ", sprintf("%.1f kWh/d", averageUsage),
                         "<br />Date:                  ", day,
                         "<br />Season:                ", season
           )
)
) %>
add_segments(x = ~minX,
             xend = ~maxX,
             y = ~averageUsage,
             yend = ~averageUsage,
             name = "Average Cons. Total",
             legendgroup = "group2",
             line = list(color = "orange", opacity = 1.0, dash = "dot"),
             hoverinfo = "text",
             text = ~ paste("<br />rolling average:      ", sprintf("%.1f kWh/d", ravgUsage),
                           "<br />Average vis. points: ", sprintf("%.1f kWh/d", averageUsage),
                           "<br />Date:                  ", day,
                           "<br />Season:                ", season
             )
)
) %>
add_segments(x = ~minX,
             xend = ~maxX,
             y = ~averageStandby*24/1000,
             yend = ~averageStandby*24/1000,
             name = "Average Standby Total",
             legendgroup = "group3",
             showlegend = FALSE,
             line = list(color = "black", opacity = 1.0, dash = "dot"),
             hoverinfo = "text",
             text = ~ paste("<br />Average standby power:      ", sprintf("%.0f W", averageStandby),
                           "<br />equals to daily energy:    ", sprintf("%.1f kWh", averageStandby*24/1000),
                           "<br />Standby percent of total cons.: ", sprintf("%.0f %%", shareStandby)
             )
)
) %>
add_segments(x = ~minX,
             xend = ~maxX,
             y = ~typEleConsVal,
             yend = ~typEleConsVal,

```

```

name = "typical household",
legendgroup = "group4",
line = list(color = "#481567FF", opacity = 1.0, dash = "dot"),
hoverinfo = "text",
text = ~ paste("<br />typical household:           ", sprintf("%.0f kWh/year", typEleConsVal*365),
              "<br />equals to daily energy:    ", sprintf("%.1f kWh/day", typEleConsVal),
              "<br />consumption of current flat: ", sprintf("%.1f kWh/day", averageUsage)
            )
) %>
add_annotations(
  x = minX,
  y = typEleConsVal,
  text = paste0("typical comparable household ", sprintf("%.1f kWh/d", typEleConsVal)),
  xref = "x",
  yref = "y",
  showarrow = TRUE,
  arrowhead = 7,
  ax = 100,
  ay = -20,
  font = list(color = "#481567FF")
) %>
add_annotations(
  x = maxX,
  y = averageUsage,
  text = paste0("Average consumption ", sprintf("%.1f kWh/d", averageUsage)),
  xref = "x",
  yref = "y",
  showarrow = TRUE,
  arrowhead = 7,
  ax = -100,
  ay = -60,
  font = list(color = "orange")
) %>
add_annotations(
  x = maxX,
  y = averageStandby*24/1000,
  text = paste0(sprintf("%.1f %%", shareStandby), " of the consumption are standby-losses"),
  xref = "x",
  yref = "y",
  showarrow = TRUE,
  arrowhead = 7,
  ax = -160,
  ay = -15,
  font = list(color = "black")
) %>
layout(
  title = main,
  xaxis = list(
    title = ""
  ),
  yaxis = list(title = "Consumption<br>(kWh/d)",
               range = c(minY, maxYUsage),
               titlefont = list(size = 14, color = "darkgrey")),
  hoverlabel = list(align = "left"),
  margin = list(l = 80, t = 50, r = 50, b = 10),
  legend = 1
)
)

```

```

fig2 <- df %>%
  plot_ly(x = ~day, showlegend = TRUE) %>%
  add_trace(data = df,
            type = "bar",
            y = ~min,
            name = "Daily standby-losses",
            legendgroup = "group3",
            marker = list(color = "darkgrey", opacity = 0.2),
            hoverinfo = "text",
            text = ~ paste("<br />daily standby:      ", sprintf("%.0f W", min),
                          "<br />rolling average:   ", sprintf("%.0f W", rminStandby),
                          "<br />Average vis. points: ", sprintf("%.0f W", averageStandby),
                          "<br />Date:                  ", day,
                          "<br />Season:                ", season
            )
  ) %>%
  add_trace(data = df,
            type = "scatter",
            mode = "markers",
            y = ~rminStandby,
            name = "Average Standby (7 days)",
            legendgroup = "group3",
            marker = list(color = "darkgrey", opacity = 0.5, symbol = "circle"),
            hoverinfo = "text",
            text = ~ paste("<br />daily standby:      ", sprintf("%.0f W", min),
                          "<br />rolling average:   ", sprintf("%.0f W", rminStandby),
                          "<br />Average vis. points: ", sprintf("%.0f W", averageStandby),
                          "<br />Date:                  ", day,
                          "<br />Season:                ", season
            )
  ) %>%
  add_segments(x = ~minX,
               xend = ~maxX,
               y = ~averageStandby,
               yend = ~averageStandby,
               name = "Average Standby Total",
               legendgroup = "group3",
               line = list(color = "black", opacity = 1.0, dash = "dot"),
               hoverinfo = "text",
               text = ~ paste("<br />Average standby power:      ", sprintf("%.0f W", averageStandby),
                             "<br />equals to daily energy:   ", sprintf("%.1f kWh", averageStandby),
                             "<br />Standby percent of total cons.: ", sprintf("%.0f %%", shareStandby)
               )
  ) %>%
  add_annotations(
    x = maxX,
    y = averageStandby,
    text = paste0(sprintf("%.0f W", averageStandby), " standby-losses on average"),
    xref = "x",
    yref = "y",
    showarrow = TRUE,
    arrowhead = 7,
    ax = -60,
    ay = -20,
    font = list(color = "black")
  ) %>%

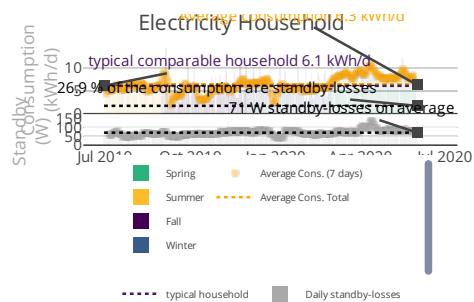
```

```

layout(
  title = "Electricity Household",
  xaxis = list(
    title = ""
  ),
  yaxis = list(title = " Standby<br>(W)",
    range = c(minY, maxYStandby),
    titlefont = list(size = 14, color = "darkgrey"),
    legend = list(orientation = 'h')),
  legend = 1
)

# calculate ratio which is visual representative for comparison
# ratio <- 1/maxYUsage * maxYStandby * 24 / 1000
ratio <- 0.3
fig <- subplot(fig1, fig2, nrows = 2, shareX = TRUE, heights = c(1-ratio, ratio), titleY = TRUE) %>%
  plotly::config(modeBarButtons = list(list("toImage")),
    displaylogo = FALSE,
    toImageButtonOptions = list(
      format = "png"
    )
)
fig

```



## 12.2 Room Temperature Reduction

### 12.2.1 Goal

As part of an energy optimization, you lower the room temperatures in a room and would now like to show the reduction effect using the time series of the room temperature sensor. In the example below you make two optimizations at different dates.

You want to create a time series plot with

- the daily median, min and max value
- the overall median of each period
- the desired setpoint

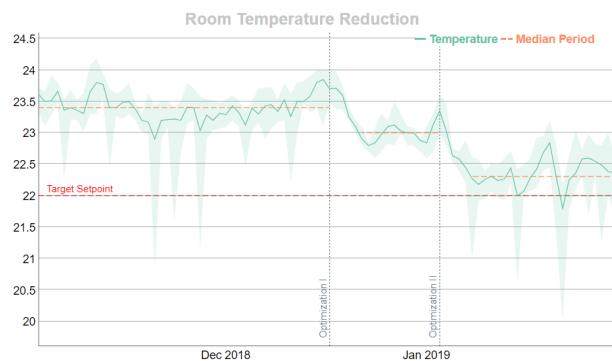


Figure 12.3: Room Temperature Reduction Plot

### 12.2.2 Data Basis

- Time series data from e.g. a temperature sensor with unaligned time intervals

### 12.2.3 Solution

Create a new script, copy/paste the following code and run it:

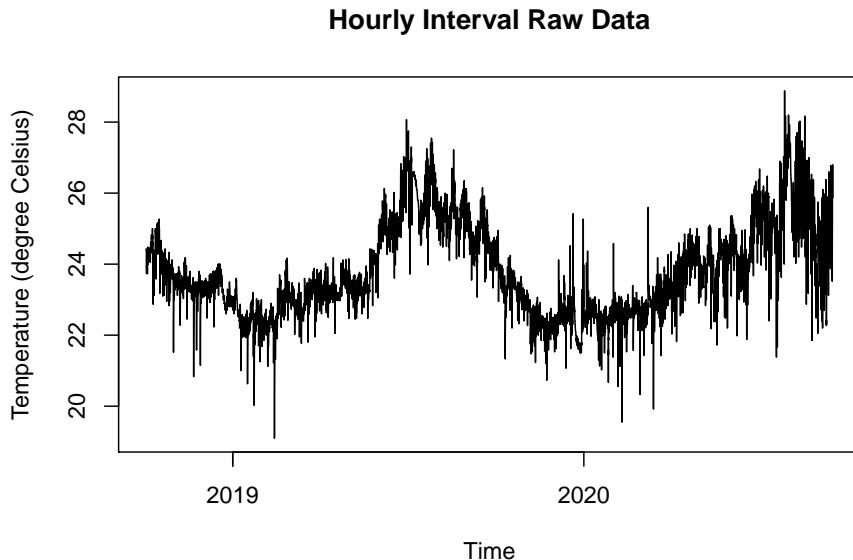


Figure 12.4: Raw Data Temperature for Room Temperature Reduction Plot

```

library(dplyr)
library(lubridate)
library(dygraphs)
library(xts)
library(redutils)
library(RColorBrewer)

# Settings
tempSetpoint = 22.0

startDate = "2018-11-01"
endDate = "2019-02-01"

optiDate1 = "2018-12-17"
optiLabel1 = "Optimization I"

optiDate2 = "2019-01-03"
optiLabel2 = "Optimization II"

optiDelayDays = 5

# read and print data
df <- read.csv("https://github.com/hslu-ige-laes/edar/raw/master/sampleData/flatTempHum.csv",
               stringsAsFactors=FALSE,
               sep =";")

# select temperature and remove empty cells

```

```

df <- df %>% select(time, FlatA_Temp) %>% na.omit()

# create column with day for later grouping
df$time <- parse_date_time(df$time, "YmdHMS", tz = "Europe/Zurich")
df$day <- as.Date(cut(df$time, breaks = "day"))
df$day <- as.Date(as.character(df$day, "%Y-%m-%d"))

# filter time range
df <- df %>% filter(day > startDate, day < endDate)

# calculate daily median, min and max of temperature
df <- df %>%
  group_by(day) %>%
  mutate(minDay = min(as.numeric(FlatA_Temp)),
         medianDay = median(as.numeric(FlatA_Temp)),
         maxDay = max(as.numeric(FlatA_Temp))
    ) %>%
  ungroup()

# shrink down to daily values and remove rows with empty values
df <- df %>% select(day, medianDay, minDay, maxDay) %>% unique() %>% na.omit()

# calculate medians for time ranges
df <- df %>%
  mutate(period = ifelse(day >= startDate & day <= optiDate1,
                         "Baseline",
                         ifelse((day >= (as.Date(optiDate1) + optiDelayDays))
                               & (day <= optiDate2),
                         "Opti1",
                         ifelse((day >= (as.Date(optiDate2) + optiDelayDays))
                               & (day <= endDate),
                         "Opti2",
                         NA)
    )))
df <- df %>%
  group_by(period) %>%
  mutate(medianPeriod = ifelse(is.na(period), NA, median(medianDay))) %>%
  ungroup() %>%
  select(-period)

# create xts object for plotting
plotdata <- xts( x=df[,-1], order.by=df$day)

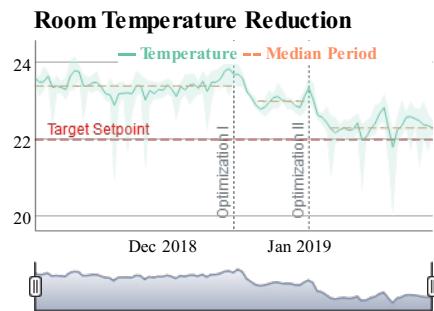
# plot graph
dygraph(plotdata, main = "Room Temperature Reduction") %>%
  dyAxis("x", drawGrid = FALSE) %>%
  dySeries(c("minDay", "medianDay", "maxDay"),
           label = "Temperature") %>%
  dySeries(c("medianPeriod"),
           label = "Median Period",
           strokePattern = "dashed") %>%
  dyOptions(colors = RColorBrewer::brewer.pal(3, "Set2")) %>%
  dyEvent(x = optiDate1,
          label = optiLabel1,
          labelLoc = "bottom",
          color = "slategray",

```

```

    strokePattern = "dotted") %>%
dyEvent(x = optiDate2,
        label = optiLabel2,
        labelLoc = "bottom",
        color = "slategray",
        strokePattern = "dotted") %>%
dyLimit(tempSetpoint,
        color = "red",
        label = "Target Setpoint") %>%
dyRangeSelector() %>%
dyLegend(show = "always")

```



#### 12.2.4 Discussion

In this example we used the dygraph package to create the graph. This package is fast and allows to show a rangeslider on the bottom of the graph. The exact same graph but without a slider is as well possible with ggplot.

Please note that the calculation of the periodic median after optimization I and II starts delayed because it takes time until the building has cooled down.

## 12.3 Building Energy Signature

### 12.3.1 Goal

You want to create a scatter plot with

- the daily mean outside temperature on the x-axis
- the daily energy consumption on the y-axis
- points colored according to season

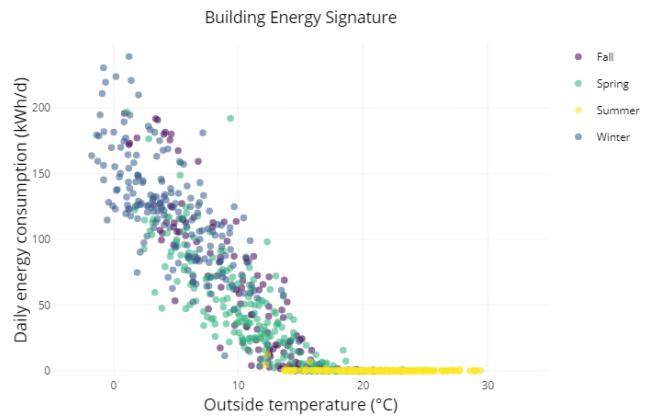
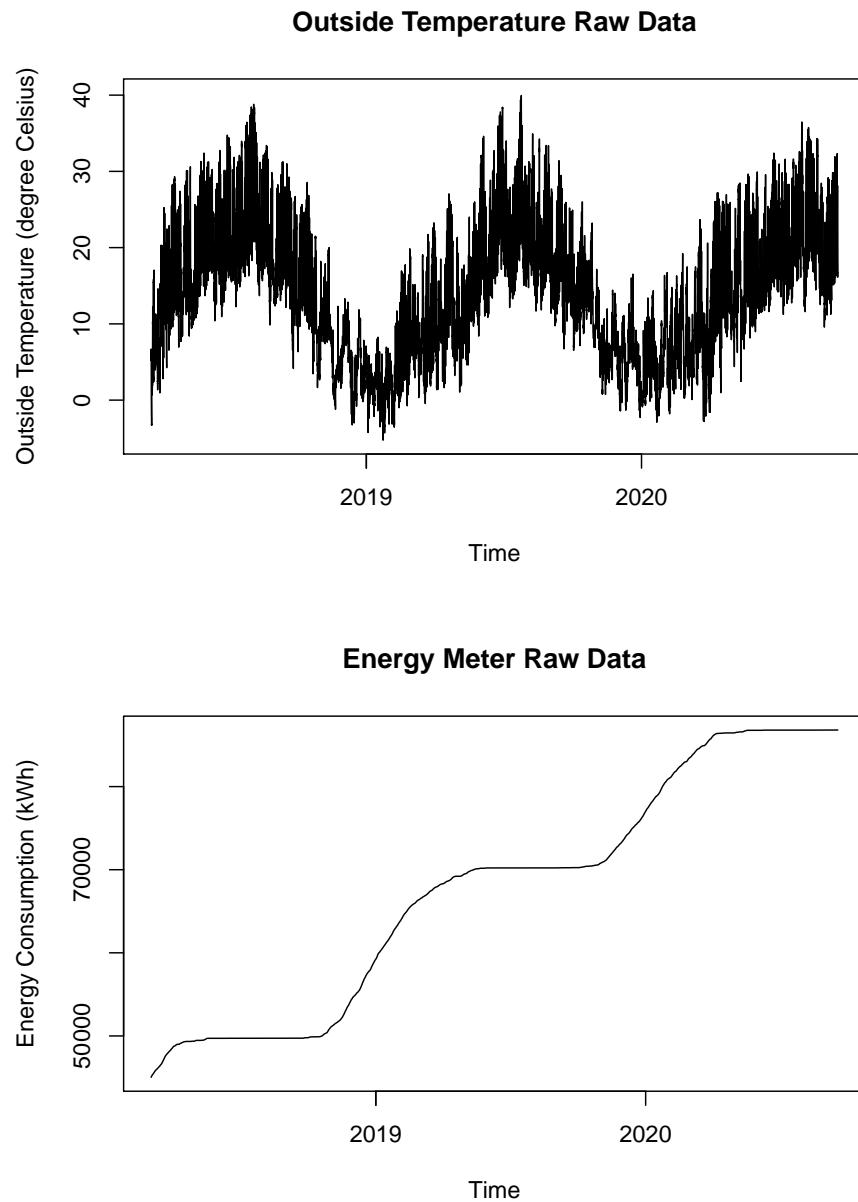


Figure 12.5: Building Energy Signature Plot

### 12.3.2 Data Basis

Two separate csv files with time series data from the outside temperature and the energy data with unaligned time intervals:



### 12.3.3 Solution

After reading in the two time series the data has to get aggregated per day and then merged. Note that during the aggregation of the energy data you have to

calculate the daily consumption from the steadily increasing meter values as well.

Create a new script, copy/paste the following code and run it:

```
library(ggplot2)
library(plotly)
library(dplyr)
library(reddotools)
library(lubridate)
# load time series data and aggregate daily mean values
dfOutsideTemp <- read.csv("https://github.com/hslu-ige-laes/edar/raw/master/sampleData/centralOutsideTemp.csv",
                           stringsAsFactors=FALSE,
                           sep =";")

dfOutsideTemp$time <- parse_date_time(dfOutsideTemp$time,
                                         order = "YmdHMS",
                                         tz = "Europe/Zurich")

dfOutsideTemp$day <- as.Date(cut(dfOutsideTemp$time, breaks = "day"))
dfOutsideTemp <- dfOutsideTemp %>%
  group_by(day) %>%
  mutate(tempMean = mean(centralOutsideTemp)) %>%
  ungroup()

dfOutsideTemp <- dfOutsideTemp %>%
  select(day, tempMean) %>%
  unique() %>%
  na.omit()

dfHeatEnergy <- read.csv("https://github.com/hslu-ige-laes/edar/raw/master/sampleData/centralHeating.csv",
                         stringsAsFactors=FALSE,
                         sep =";")

dfHeatEnergy <- dfHeatEnergy %>%
  select(time, energyHeatingMeter) %>%
  na.omit()

dfHeatEnergy$time <- parse_date_time(dfHeatEnergy$time,
                                       orders = "YmdHMS",
                                       tz = "Europe/Zurich")

dfHeatEnergy$day <- as.Date(cut(dfHeatEnergy$time, breaks = "day"))
dfHeatEnergy <- dfHeatEnergy %>%
  group_by(day) %>%
  mutate(energyMax = max(energyHeatingMeter)) %>%
  ungroup()

dfHeatEnergy <- dfHeatEnergy %>%
  select(day, energyMax) %>%
  unique() %>%
  na.omit()

dfHeatEnergy <- dfHeatEnergy %>%
  mutate(energyCons = energyMax - lag(energyMax)) %>%
  select(-energyMax) %>%
  na.omit()
```

```

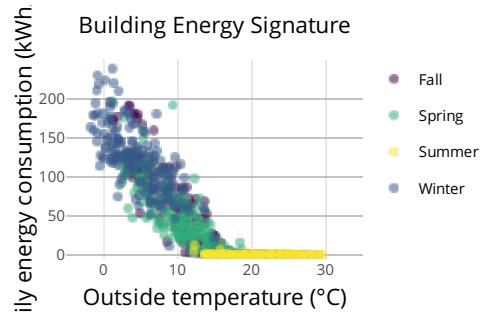
# merge the data in a tidy format
df <- merge(dfOutsideTemp, dfHeatEnergy, by = "day")

# calculate season
df <- df %>% mutate(season = reutils::getSeason(df$day))

# static chart with ggplot
plot <- ggplot2::ggplot(df) +
  ggplot2::geom_point(aes(x = tempMean,
                           y = energyCons,
                           color = season,
                           alpha = 0.1,
                           text = paste("</br>Date: ", as.Date(df$day),
                                       "</br>Temp: ", round(df$tempMean, digits = 1), "\u00B0C",
                                       "</br>Energy: ", round(df$energyCons, digits = 0), "kWh/d",
                                       "</br>Season: ", df$season)
  ) +
  scale_color_manual(values=c("#440154", "#2db27d", "#fde725", "#365c8d")) +
  ggtitle("Building Energy Signature") +
  theme_minimal() +
  theme(
    legend.position="none",
    plot.title = element_text(hjust = 0.5)
  )

# interactive chart
plotly::ggplotly(plot, tooltip = c("text")) %>%
  layout(xaxis = list(title = "Outside temperature (\u00B0C)",
                       range = c(min(-5,min(df$tempMean)), max(35,max(df$tempMean))), zeroline = F),
         yaxis = list(title = "Daily energy consumption (kWh/d)",
                     range = c(-5, max(df$energyCons) + 10)),
         showlegend = TRUE
  ) %>%
  plotly::config(displayModeBar = FALSE, displaylogo = FALSE)

```



#### 12.3.4 Discussion

This visualization allows a quick detection of malfunctions and provides valuable information on the energy efficiency of the building.

- A constant indoor temperature is assumed.
- It is also assumed that the outside temperature is the parameter with the greatest influence on heating energy consumption.
- This method is suitable for buildings with stable internal heat loads and relatively low passive solar heat loads.

# Appendix A

## Packages in R

Many functions of R are not pre-installed and must be loaded manually. R packages are similar to libraries in C, Python etc. An R package bundles useful functions, help files and data sets. You can use these functions within your own R code once you load the package.

The following chapters describe how to install, load, update and use packages.

## A.1 Installing a Package

The easiest way to install an R Package is to use the RStudio tab “Packages”:

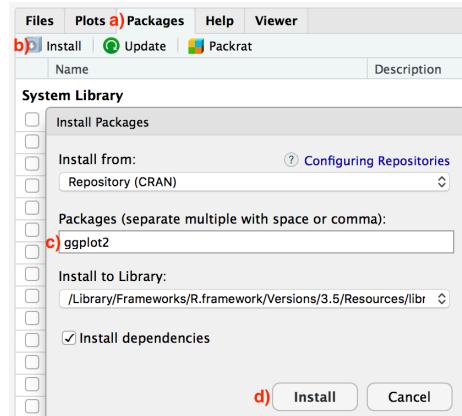


Figure A.1: Install packages via RStudio GUI

- Click on the “Packages” tab
- Click on “Install” next to Update
- Type the name of the package under “Packages, in this case type ggplot2
- Click “Install”

This will search for the package “ggplot” specified on a server (the so-called CRAN website). If the package exists, it will be downloaded to a library folder on your computer. Here R can access the package in future R sessions without having to reinstall it.

An other way is to use the `install.packages` function. Open R (if already opened please close all projects) and type the following at the command line:

```
install.packages("ggplot2")
```

If you want to install a package directly from github, the package “devtools” must be installed first:

```
install.packages("devtools")
library(devtools)
install_github("hslu-ige-laes/redutils")
```

## A.2 Loading a Package

If you have installed a package, its functions are not yet available in your R project. To use an R package in your script, you must load it with the following command:

```
install.packages("ggplot2")
```

## A.3 Upgrading Packages

R packages are often constantly updated on CRAN or GitHub, so you may want to update them once in a while with:

```
update.packages(ask = FALSE)
```