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# Estonian test reference year for energy calculations

Targo Kalamees[a] and Jarek Kurnitski[b]

[a] Chair of Building Physics and Architecture, Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia; kalamees@uninet.ee
[b] HVAC Laboratory, Helsinki University of Technology, P.O. Box 4100, FI-02015 HUT, Finland; jarek.kurnitski@hut.fi

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**Abstract.** Building simulation is increasingly being used in energy performance and indoor climate analysis and heating, ventilation and air conditioning systems design. Simulation requires hourly weather data. In this study Estonian climate was analysed to construct a test reference year for heating and cooling energy calculations and simulations according to a new standard, ISO15927-4. The selection was made on the basis of temperature, humidity, and global solar radiation and wind speed recordings at six weather stations over a period of 31 years, from 1970 to 2000. The constructed test reference year contains typical months from a number of different years. The average number of heating degree-days was calculated from data at six locations. The test reference year has many applications, including energy consumption and energy performance certificate calculations according to the directive about energy performance in buildings.

**Key words:** climate analysis, test reference year, heating degree-days, thermal performance.

## 1. INTRODUCTION

Building simulation for energy consumption calculations as well as for the planning of active or passive solar energy systems, has been more and more widely used in recent decades. Rising prices of energy and the need to reduce the amount of greenhouse gases, released into the atmosphere, are among the reasons for this. Many calculation methods and simulation tools can be used to design individual buildings, to evaluate energy efficiency and to improve the energy and thermal performance of existing buildings. Indoor climate and energy simulation programs are widely used for the comparison of design alternatives and for optimizing heating, ventilation and air conditioning (HVAC) systems and energy performance calculations. Simulation tools can provide a better understanding of the performance of HVAC systems and the interaction between HVAC systems and the whole building. The calculation and simulation results depend heavily on the input parameters including boundary conditions. One boundary condition for indoor climate and energy simulation programs is hourly outdoor climate data.

As the residential and tertiary sector, the major part of which is accounted for by buildings, accounts for more than 40% of the final energy consumption in the European Union; the Energy Performance Building Directive (EPBD) [1] requires the energy performance of buildings to be enhanced. To make it possible for consumers to compare and assess the energy performance of a building, an energy performance certificate will soon be required in the member states of the European Union. The energy performance of buildings should be calculated on the basis of a standardized methodology, with the same outdoor climate. It demands specification of a standardized reference year.

The Estonian climate has been investigated for building simulations and energy calculations in many earlier studies. Kõiv [2] calculated the number of heating degree-days in Tallinn in 26 years (1967–1992) for several mean room temperatures. He also gave the average duration of the daily external temperature in Tallinn. Jõgioja and Pahapill [3] compiled Estonian climate data for building specialists. This publication gives a general overview of the Estonian climate. The coldest average temperatures for 1 to 10 days for designing building heating systems are also presented. Kalamees and Vinha [4] analysed the Estonian climate and selected moisture reference years for hygrothermal calculations. Two different hygrothermally critical years were chosen: a critical year for the risk of water vapour condensation and a critical year for the risk of mould growth. Kusnetsov and Kõiv [5] analysed weather data from the Tartu Meteorological Station in the years 1991–2000 and selected the outdoor climate for the simulation and analysis of the thermal performance of an apartment building. On the basis of monthly average temperatures a specific reference month was chosen, which was closest to the outdoor temperatures measured at the Tartu Meteorological Station in the years 1991–2000. By choosing a specific month of a year, the total solar radiation level was also taken into account.

In this study, the Estonian climate data from six meteorological stations over the 31-year period from 1970 to 2000 have been analysed to develop a test reference year for energy calculations.

## 2. WEATHER DATA FOR ENERGY CALCULATIONS

Keeble [6] has defined three types of hourly weather data for use in building energy simulation:

- Multi-year datasets: they are fundamental and include a substantial amount of information for a number of years.
- Typical years: a typical or reference year is a single year of hourly data selected to represent the range of weather patterns that would typically be

found in a multi-year dataset. The definition of a typical year depends on how it satisfies a set of statistical tests relating it to the parent multi-year dataset.

- Representative days: they are hourly data for some average days selected to represent typical climatic conditions. Representative days are economical for small-scale analysis and are often found in simplified simulation and design tools.

A reference year for energy calculations should represent mean values of main climate parameters that are as close as possible to long-time mean values. Lund [7] has suggested three main requirements for a reference year.

- True frequencies, i.e., as near as possible to true mean values over a longer period, e.g., a month, and a natural distribution of higher and lower values for single days.
- True sequences, i.e., the weather conditions must have a duration and follow each other in a similar manner to often-recorded conditions for the location.
- True correlation between different parameters, i.e. temperature, solar radiation, cloud cover and wind.

Over the past 30 years, several weather data sets have been suggested for use in building energy simulations. In the following paragraphs the most common selection methods are given.

The principle for determining the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) test reference year (ASHRAE TRY) [8] is to eliminate those years that contain months with extremely high or low monthly mean dry-bulb air temperatures (DBT) until only one year, the ASHRAE TRY, remains. The months are arranged in the order of importance for energy comparisons. For example, the hottest July and the coldest January are assumed to be the most important; the coolest October and the warmest April are considered as the most unimportant. Depending on climatic regions, this order may change. The first step in the selection process is to mark all 24 extreme months according to the rankings. If two or more years remain without any marked months, elimination will be repeated with the next-to-hottest July, the next-to-coldest January, and so on, until one year is left without marked months. The ASHRAE TRY is an actual year.

The typical meteorological year (TMY) [9,10] consists of twelve typical meteorological months (TMM) selected from a multi-year weather database. The selection of a TMM is based on the statistical analysis and evaluation of four weather parameters: global solar radiation (GSR), DBT, dew-point air temperature (DPT), and wind speed (WSP). A set of nine parameters is included in the selection: daily maximum, daily minimum, daily mean DBT and DPT, daily maximum and daily mean WSP, and daily global solar radiation (GSR). A nonparametric method, known as the Finkelstein–Schafer (FS) statistic [11], is used to determine the candidate months by comparing the yearly cumulative distribution to long-term distributions. Climatic parameters are weighted in terms of relative importance from 1/24 to 12/24. The highest weighting is given by the originators of the method to solar radiation as it was intended for use primarily in assessing solar energy conversion systems and buildings. In the final selection the intention is to select a month that has a small FS value, small deviation and typical run structure. The TMY data contain months from a number of different years.

The basic method used to select the weather year for energy calculations (WYEC) [12] is to determine the individual month with the average DBT, closest to the long-term monthly average; there are no abnormalities and the DBT is within 0.1 °C of the long-term monthly average. If the chosen month is outside the 0.1 °C limit, then a month from another year, close to the mean but below it, is chosen and days from this month are substituted into the chosen month until its average DBT is within 0.1 °C of the long-term average. The WYEC data contain months from a number of different years. The selected month may include climatic data from month of another year. The WYEC data set format was reorganized and the WYEC2 data format was developed by Stoffel and Rymes [13].

International weather for energy calculations (IWEC) [14] and the Canadian weather year for energy calculations (CWEC) [15] use a selection process similar to the TMY, but with different weighting factors.

The ISO 15927-4:2005 [16] method is close to the Danish selection method [17]. DBT, GSR and air humidity were taken as the primary parameters for selecting the best month to form the reference year. The selection process is specified so as to try to obtain the mean values of individual parameters, frequency distribution of individual parameters, and correlations between the different variables within each month, as close as possible to the corresponding calendar month of the long-term data. This selection procedure was used in this study and is described in greater detail in Section 4.

In addition to these common standardized selection methods, some countries have developed their own methods, which are modifications of common methods or completely new. The Finnish test-year [18] is an actual historical year (1979) and was selected mainly on the basis of monthly mean temperatures and global radiation levels. In the first selection round, the method discarded those years for which monthly average temperatures for the whole year or a single month differed from long-term (1968–1983) average data. From the remaining 3 to 5 years the selected test-year took into account average DBT, GSR and the interaction of DBT and GSR. Additionally, the number of heating degree-days and daily and hourly variations of DBT and GSR were taken into account. Lam et al. [19] developed TMY for Hong Kong. Apart from the FS statistic, the non-parametric Kolmogorov–Smirnov (KS) test statistic [20] was also used for the analysis. While the FS statistic is based on the magnitude of the cumulative distribution frequency, the KS statistic is based on the maximum deviation. In Japan, the automated meteorological data acquisition system (AMeDAS) is the most dense array system for weather data acquisition. Expanded AMeDAS weather data for building energy calculation have been developed by Akasaka et al. [21]. The candidate month and typical month are selected from weather data by using a multistep filtering process. Mean temperature of each month is compared with the multiyear average for this month. When the values have a deviation within the standard deviation of the multiyear data, values identified by the years are considered as candidates for the specific month at this stage. A similar process was performed for global solar radiation, humidity ratio, precipitation and wind speed. Finkelstein–Schafer statistic was then used to indicate the deviation of daily averages of the same weather data parameters. In calculating the weighting factors, the effects of temperature, humidity ratio and horizontal global irradiation on the heating loads of the building were considered.

## 3. CLIMATIC DATA

The main climatic boundary divides the territory of Estonia into two climatic areas [22–25]: the coastal area, which is directly influenced by the sea, and the inland area. The western island region, the West Estonian region, and the northern coastal region make up the coastal area. The North Estonian region and South Estonian region make up the inland area. The principal territorial differences in climate are due to the adjacent Baltic Sea. The boundary line between the two main climatic areas is shown in Fig. 1.

Six meteorological stations, three from both climatic areas, were selected for the analysis. They were chosen according to the climate and the building density of the areas. Tallinn, Kuressaare, and Pärnu represent the coastal area and Tartu, Väike-Maarja and Võru the inland area. Tallinn and Tartu have the highest rate of occupancy and building activity in Estonia. Kuressaare represents the western island region and Pärnu the West Estonian region in the coastal area. Väike-Maarja represents NE Estonia and Võru represents the South Estonian highland region.


**Fig. 1.** Climatic areas of the territory of Estonia. Meteorological stations, whose data were used in the analysis of this paper, are indicated by large dots.

**Table 1.** Locations of the meteorological stations

| Station | Longitude | Latitude | Altitude, m |
|---|---|---|---|
| Tallinn 1970–04.1980 | N 59°25′ | E 24°48′ | 39 |
| Tallinn 05.1980–2000 | N 59°23′54″ | E 24°36′15″ | 33 |
| Kuressaare | N 58°13′53″ | E 22°30′18″ | 3 |
| Pärnu | N 58°22′53″ | E 24°30′12″ | 3 |
| Tartu 1970–1997 | N 58°18′ | E 26°44′ | 62 |
| Tõravere 1998–2000 | N 58°15′50″ | E 26°27′42″ | 70 |
| Väike-Maarja | N 59°08′27″ | E 26°13′52″ | 120 |
| Võru | N 57°50′46″ | E 27°01′10″ | 82 |

According to the World Meteorological Organization, the minimum return period for climatic analysis is 30 years. In this study, temperature, relative humidity, and wind data at three-hour steps and global solar radiation at one-hour steps over the 31-year period from 1970 to 2000 were used. The Estonian Meteorological and Hydrological Institute (http://www.emhi.ee) provided all climatic data. Locations of the meteorological stations are shown in Table 1.

There were some deficiencies in the climatic data. In Kuressaare no data was available during a 34 month period at 00 and 03 AM for temperature and relative humidity and in Pärnu during a seven month period at 00, 03, and 06 AM temperature and relative humidity data were missing. In these cases, linear interpolation was used to substitute missing data. In Võru there was no temperature and relative humidity data during a two month period. In this case, for the data of June and August, a period of 30 years instead of 31 years was used.

In Tartu episodic measurements of solar radiation were carried out already at the beginning of the 20th century and in the 1930s. Complete measurements of solar radiation in Tartu–Tõravere meteorological station began in 1965. The direct normal radiation and diffuse radiation (one minute averages and daily totals) are measured directly, from which global radiation is calculated [[26]].

## 4. PROCEDURE OF CONSTRUCTION OF THE TEST REFERENCE YEAR

In this study, the ISO 15927-4:2005 [[16]] method was used to construct the test reference year. The primary selection was made on the basis of dry-bulb temperature, global solar radiation, and water vapour pressure (WVP). The wind speed was used for secondary selection. As GSR data are available only for Tartu (not measured at other selected stations), the months of the test reference year are selected at this meteorological station. To guarantee that the selected year represents the whole Estonian climate as completely as possible, in the reference long-term data, temperature and humidity from all six meteorological stations over 31 years are represented.

For each climatic parameter $p$, daily means $\overline{p}$ are calculated. For each calendar month $m$, the cumulative distribution function $\Phi_{p,m,i}$ of daily means over all the years in the data set is calculated. For each year $y$ of the data set, the cumulative distribution function $F_{p,y,m,i}$ of the daily means within each calendar month is calculated. For each calendar month $m$ the Finkelstein–Schafer statistic for parameter $p$, $FS_{p,y,m}$ for each year $y$ of the data set is calculated:

$$FS_{p,y,m} = \sum_{i=1}^{n} \left| F_{p,y,m,i} - \Phi_{p,m,i} \right|. \tag{1}$$

To normalize $FS_{p,y,m}$ for months of varying lengths, the results of Eq. (1) are divided by the number of days of the month (28, 29, 30, or 31). Monthly average $FS_{p,y,m}$ values of climate parameters DBT, GSR and WVP are added together and the same months of all years are ranked in the order of the increasing value of $FS_{p,y,m}$. From each calendar month, three candidate months with the lowest total ranking are selected. The monthly deviation of the wind speed of the three months is compared with the corresponding multi-year mean of calendar months. The month with the lowest deviation in wind speed is selected as the best month for inclusion in the test reference year.

Figure 2 shows the principle of the selection process. The bold black curve shows the 31-year daily average temperature data from the six weather stations in January. The dotted curve shows the selected month for Tartu, where the monthly

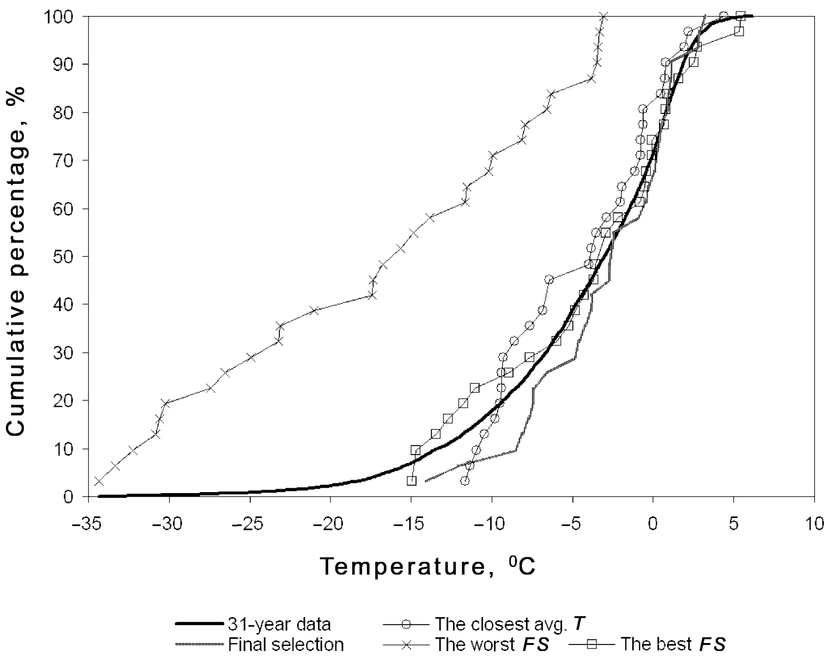



**Fig. 2.** Comparison of daily average temperatures in January.

average temperature is closest to the 31-year data. The curve, marked with squares, has the smallest *FS* statistic, when the 31-year temperature data and the corresponding month's temperature are compared. The curve, marked with circles, shows the daily average temperature of the final selection, when temperature, humidity, solar radiation and wind are taken into account. The curve, marked with crosses, shows the month with the biggest *FS* statistic. This month was also the coldest January during the 31-year period.

## 5. RESULTS

### 5.1. Test reference year

The primary selection of the month for the test reference year was made by using data of all the six weather stations for the whole 31-year period. Years are ranked according to the *FS* statistic and in Tables 2 to 4 five years with the lowest *FS* statistic are shown. Bold numbers show months with the lowest *FS* statistic when monthly average *FS* statistics of temperature, humidity and solar radiation are added together. For comparison, the same data of the Tartu meteorological station is shown.

The final selection of the month of the test reference year was made considering wind speed. Three months (the lowest total rankings are shown by bold numbers in Tables 2, 3 and 4) wind speeds are compared with the wind speed data from the corresponding multi-year calendar month. The month with the lowest deviation in wind speed is selected as the best month for inclusion in the test reference year. Table 5 shows the main climatic parameters of the month selected for the test reference year and the average data over a 31-year period from the 6 meteorological stations.

**Table 2.** Temperature selection for the test reference year

| Rank | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Long-term data: six meteorological stations, 31 years | | | | | | | | | | | |
| 1. | **1988** | 1987 | 1994 | **1995** | **1985** | 1981 | **1982** | 1975 | 1981 | 1999 | **1990** | **1979** |
| 2. | 1999 | **1988** | 1993 | 1982 | **1977** | **1974** | **1970** | **1971** | **1982** | 1981 | 1976 | **1980** |
| 3. | **1994** | **1973** | **1973** | 1971 | **1982** | 1998 | 1971 | **1990** | **1998** | **1990** | 1972 | **1983** |
| 4. | 1984 | **1991** | 1978 | 1977 | 1976 | 2000 | 1981 | 1995 | 1997 | **1983** | **1989** | 1993 |
| 5. | 2000 | 1972 | 1972 | **1993** | 1987 | **1984** | 1995 | 1999 | 1980 | 1987 | 1974 | 1994 |
| | Long-term data: Tartu, 31 years | | | | | | | | | | | |
| 1. | 1988 | 1987 | 1993 | 1995 | 1977 | 1998 | 1982 | 1975 | 1982 | 1987 | 1972 | 1979 |
| 2. | 1973 | 1991 | 1994 | 1996 | 1985 | 1981 | 1971 | 1999 | 1981 | 1990 | 1990 | 1989 |
| 3. | 1999 | 1988 | 1977 | 1993 | 2000 | 1997 | 1970 | 1990 | 1991 | 1999 | 1970 | 1987 |
| 4. | 1995 | 1981 | 1978 | 1980 | 1976 | 1989 | 1981 | 1995 | 1997 | 1977 | 1989 | 1983 |
| 5. | 1984 | 1999 | 1972 | 1982 | 1998 | 1992 | 1991 | 1971 | 1972 | 1975 | 1976 | 1993 |

**Table 3.** Humidity selection for the test reference year

| Rank | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Long-term data: six meteorological stations, 31 years | | | | | | | | | | | |
| 1. | **1988** | 1987 | 1993 | **1970** | 1987 | **1974** | **1982** | 1989 | 1983 | **1983** | **1989** | **1980** |
| 2. | 1999 | 1972 | **1973** | **1995** | **1977** | 1991 | 1999 | 1979 | 1980 | 1977 | **1990** | **1983** |
| 3. | 2000 | **1973** | **1999** | 1975 | **1985** | **1983** | 1986 | 1970 | 1970 | 1999 | 1972 | **1979** |
| 4. | **1994** | **1991** | 1994 | 1972 | 1989 | 1997 | 1990 | 2000 | **1991** | **1990** | 1976 | 1999 |
| 5. | 1984 | **1988** | 1977 | 1977 | 1990 | **1984** | **1991** | **1971** | **1998** | 1982 | **1999** | 1991 |
| | Long-term data: Tartu, 31 years | | | | | | | | | | | |
| 1. | 1988 | 1972 | 1994 | 1970 | 1987 | 1974 | 1994 | 1989 | 1998 | 1990 | 1989 | 1979 |
| 2. | 1986 | 1991 | 1999 | 1992 | 1977 | 1991 | 1983 | 1970 | 1991 | 1977 | 1972 | 1983 |
| 3. | 1995 | 1987 | 1997 | 1972 | 1996 | 1983 | 1999 | 1971 | 1985 | 1987 | 1983 | 1989 |
| 4. | 1974 | 1981 | 1993 | 1995 | 1985 | 1997 | 1982 | 1981 | 1979 | 1983 | 1999 | 1984 |
| 5. | 1999 | 1973 | 1973 | 1993 | 1979 | 1984 | 1993 | 1992 | 1982 | 1998 | 1990 | 1987 |

**Table 4.** Solar radiation selection for the test reference year

| Rank | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Long-term data: Tartu, 31 years | | | | | | | | | | | |
| 1. | **1997** | **1988** | **2000** | 1986 | **1985** | 2000 | 1987 | 1972 | 1976 | 2000 | **1989** | 1977 |
| 2. | 1992 | 1993 | **1973** | 1991 | 1999 | 1973 | 1976 | 1976 | **1982** | 1978 | 1994 | 1981 |
| 3. | 1977 | 1982 | 1986 | 1982 | 1981 | 1978 | 1992 | **1982** | **1991** | 1993 | 1983 | 1974 |
| 4. | 1995 | 1977 | 1977 | 1976 | 1974 | 1977 | **1982** | 1991 | 1977 | **1991** | 1996 | 1975 |
| 5. | **1994** | **1991** | **1999** | 1978 | 2000 | 1971 | 1980 | **1990** | 1983 | 1984 | **1999** | 1970 |

**Table 5.** Climatic data for the test reference year (TRY) and average data over the 31-year period (Avg.)

| Month | Year | Dry-bulb air temperature, monthly avg. °C | | | Relative humidity, monthly avg. % | | Wind speed, monthly avg. m/s | | Direct norm. radiation, monthly sum MJ/m$^2$ | | Diff. radiation on horiz. surf., monthly sum MJ/m$^2$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TRY | 1991 | Avg. | TRY | Avg. | TRY | Avg. | TRY | Avg. | TRY | Avg. |
| Jan | 1994 | –3.0 | –2.2 | –4.5 | 90 | 87 | 5 | 4 | 35.0 | 61.3 | 39.2 | 36.2 |
| Feb | 1991 | –5.2 | –5.2 | –5.1 | 89 | 85 | 4 | 4 | 93.4 | 126.2 | 82.0 | 78.3 |
| Mar | 1973 | –0.1 | 0.0 | –1.4 | 76 | 81 | 4 | 4 | 308.1 | 265.6 | 144.2 | 151.9 |
| Apr | 1970 | +4.0 | +5.3 | +4.2 | 77 | 75 | 4 | 4 | 254.4 | 346.9 | 190.2 | 203.7 |
| May | 1977 | +11.2 | +9.1 | +10.6 | 70 | 68 | 4 | 3 | 493.3 | 538.2 | 269.6 | 262.2 |
| Jun | 1984 | +14.1 | +13.8 | +14.9 | 73 | 73 | 3 | 3 | 497.8 | 544.3 | 306.1 | 281.5 |
| Jul | 1991 | +17.2 | +17.2 | +16.9 | 77 | 76 | 3 | 3 | 606.1 | 520.3 | 290.8 | 283.6 |
| Aug | 1990 | +15.7 | +16.8 | +15.8 | 81 | 79 | 3 | 3 | 453.6 | 423.4 | 229.7 | 230.9 |
| Sep | 1982 | +10.8 | +10.9 | +10.8 | 82 | 83 | 4 | 3 | 259.0 | 267.8 | 161.3 | 148.8 |
| Oct | 1990 | +5.8 | +6.6 | +6.0 | 87 | 85 | 4 | 4 | 143.8 | 164.4 | 82.9 | 82.9 |
| Nov | 1989 | –0.1 | +3.3 | +0.9 | 91 | 88 | 4 | 4 | 68.2 | 58.4 | 37.0 | 36.1 |
| Dec | 1979 | –2.5 | –1.0 | –2.6 | 86 | 89 | 5 | 4 | 49.7 | 39.6 | 20.8 | 23.5 |
| Annual avg. | | +5.7 | +6.3 | +5.6 | 81 | 81 | 4 | 4 | 271.9 | 279.7 | 154.5 | 152.2 |

Figures 3, 4, and 5 show the hourly temperature, relative humidity and total solar radiation data for the test reference year (each month is from a different year, see Table 5).

After the selection of the twelve calendar months for the test reference year, the months should be joined together. The first and the last eight hours [16] of each month are adjusted by smoothing them with a cubic spline (Fig. 6). The adjustment also includes the last eight hours of December and the first eight

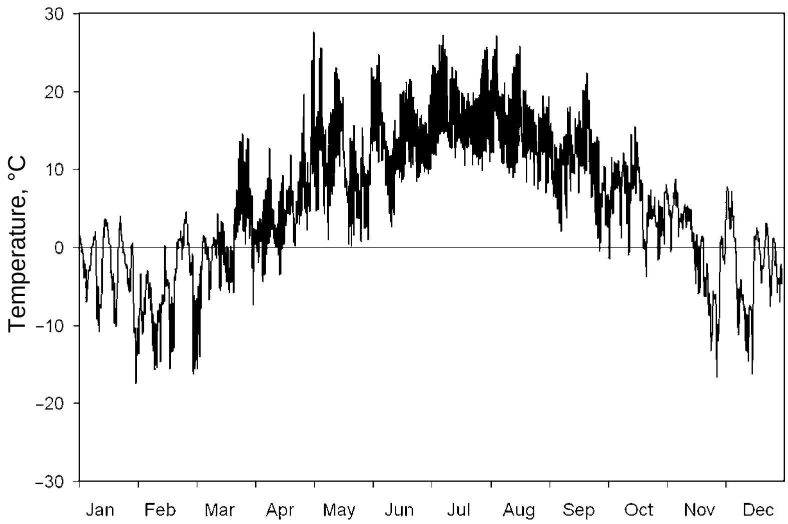



**Fig. 3.** Temperature of the test reference year.

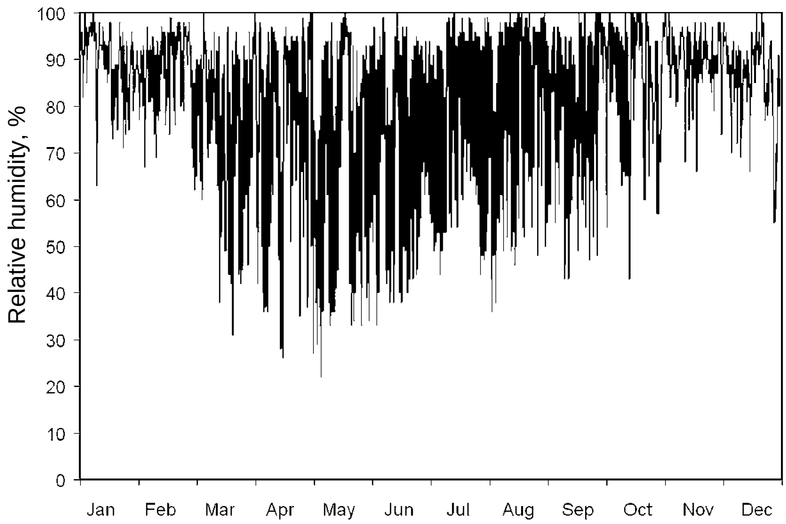



**Fig. 4.** Relative humidity of the test reference year.

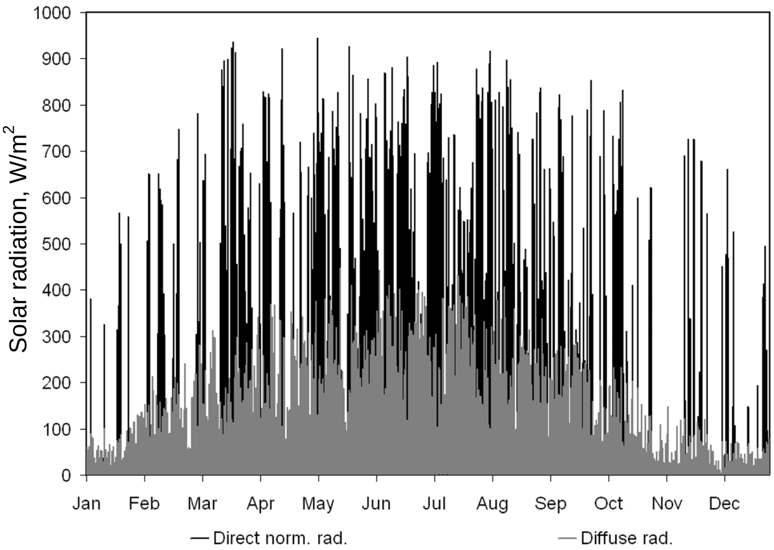



**Fig. 5.** Direct normal radiation and diffuse radiation on horizontal surface of the test reference year.

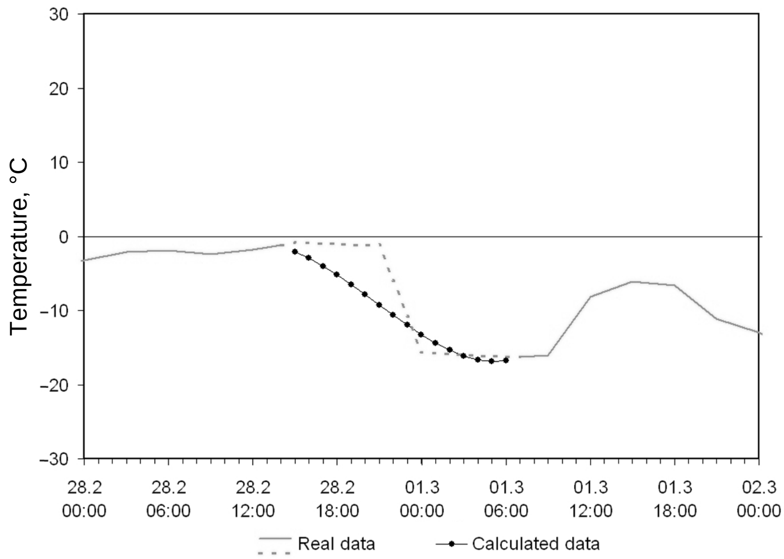



**Fig. 6.** Cubic spline connecting data of two months.

hours of January, so that the test reference year can be used repeatedly in simulations. As temperature, humidity and wind are measured at three-hour steps, data should be interpolated in order to get hourly data.

Because wind direction and velocity change a great deal during a day, these climatic elements are not smoothed. Similarly, solar radiation, which is zero at midnight, is also not smoothed.

For comparative purposes, one homogeneous year that is closest to the 31-year data, was also selected. This year was selected on the basis of air temperature, air humidity and total solar radiation by comparing one year's annual average *FS* statistic with the *FS* statistic of the 31-year data (see Section 4). The homogeneous year, closest to the long-term data, was 1991 in Tartu. The comparison of the test reference year, the year 1991, and the long-term data is shown in Figs. 7 and 8.

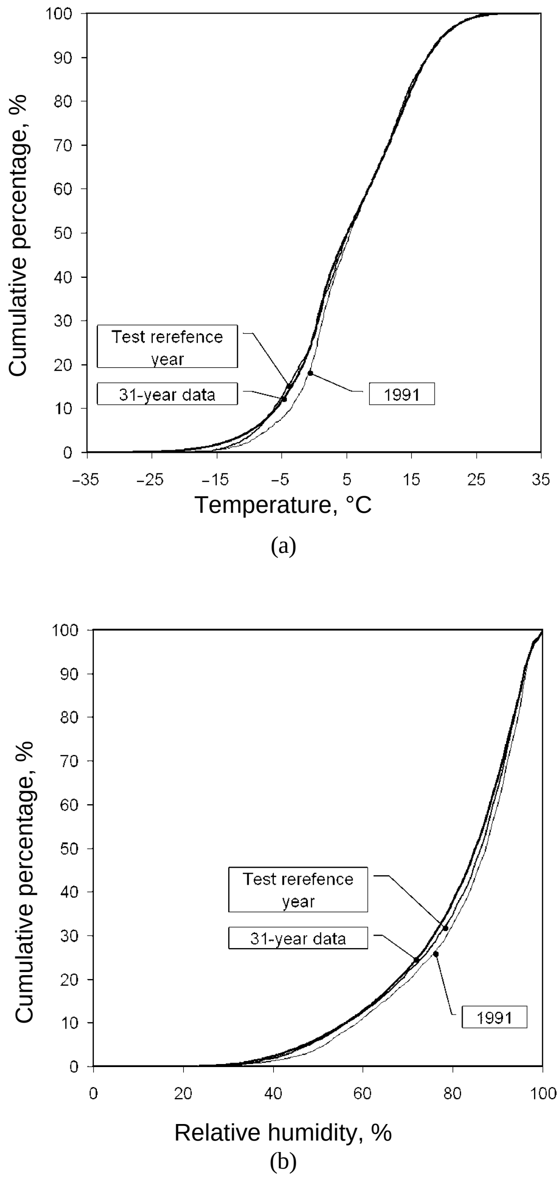
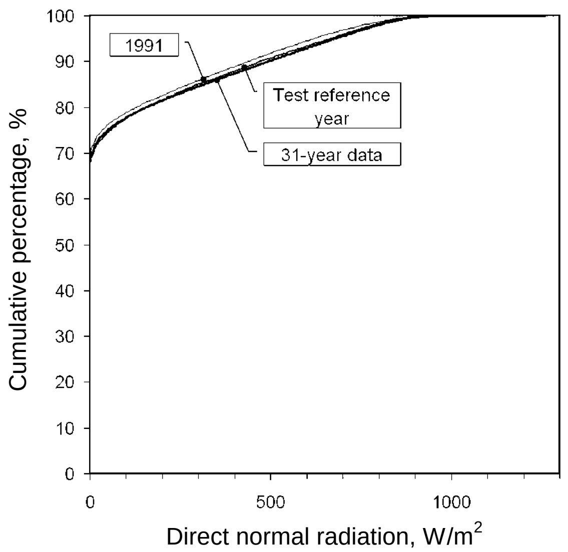
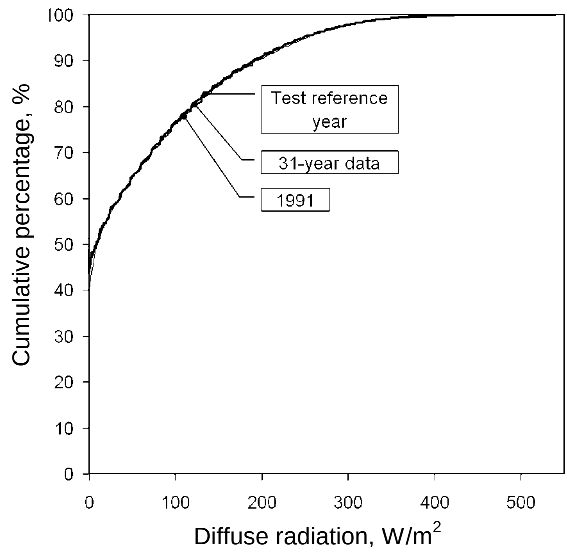



**Fig. 7.** Cumulative distribution of temperature (a) and relative humidity (b).




(a)




(b)

**Fig. 8.** Cumulative distribution of direct normal radiation (a) and diffuse radiation on horizontal surface (b).

## 5.2. Heating degree-days

Simple heating energy calculation methods are often based on heating degree-days. They use the fact that heating energy demand in steady state calculations is proportional to the difference between the indoor and the outdoor temperature. Depending on the calculation method, either internal gains are calculated and correct value for the indoor temperature is used, or internal gains are compensated by using lower indoor temperature. By taking into account internal gains, special attention should be paid to modern well-insulated buildings. Heating degree-days were calculated for all six locations. The duration of the heating season was not taken into account, i.e. calculation was not stopped when the outdoor temperature rose above +12 °C in spring or was higher than +10 °C in autumn, as is the case with some old heating degree-day calculation methods. It is considered that modern heating systems are available on demand and in a cold climate long heating season breaks are not common any more. The number of heating degree-days per year, $S_{T_{in}}$, was calculated as the sum of the differences between the indoor temperature and the daily average outdoor temperature

$$S_{T_{in}} = \sum_{i=1}^{n} (T_{in} - T_{d,out_i})^+ , \quad (2)$$

where $T_{in}$ is the indoor temperature, $T_{d,out_i}$ is the daily average outdoor temperature of the day $i$, "+" indicates that only positive values are added, and $n$ is the total number of days in the year.

The annual average numbers of heating degree-days for some indoor temperatures are shown in Table 6. The 31-year average data, the selected test reference year, and the year 1991 from Tartu (the closest homogeneous year to the 31-year average data) are given as well. The annual average numbers $S_{21}$ of heating degree-days during 31 years is shown in Fig. 9. The monthly average numbers of heating degree-days and average outdoor temperatures are shown in Table 7.

**Table 6.** The annual average number of heating degree-days $S_{T_{in}}$ for some indoor temperatures $T_{in}$

| Meteorological station | $T_{in}$, °C | | | |
|---|---|---|---|---|
| | 15 | 17 | 19 | 21 |
| Tallinn | 3604 | 4249 | 4940 | 5656 |
| Kuressaare | 3316 | 3950 | 4635 | 5349 |
| Pärnu | 3472 | 4075 | 4745 | 5448 |
| Tartu | 3700 | 4330 | 5009 | 5718 |
| Väike-Maarja | 3936 | 4588 | 5279 | 5994 |
| Võru | 3620 | 4234 | 4898 | 5609 |
| 31-year average from 6 locations | 3608 | 4238 | 4917 | 5629 |
| The test reference year | 3528 | 4160 | 4850 | 5568 |
| 1991, Tartu | 3340 | 3978 | 4664 | 5371 |

**Table 7.** The monthly average number of heating degree-days $S_{21}$ and outdoor temperatures $T_{out}$, °C

| Month | Meteorological station | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tallinn | | Kuressaare | | Pärnu | | Tartu | | Väike-Maarja | | Võru | | 31-year average from 6 locations | | The test reference year | |
| | $S_{21}$ | $T_{out}$ | $S_{21}$ | $T_{out}$ | $S_{21}$ | $T_{out}$ | $S_{21}$ | $T_{out}$ | $S_{21}$ | $T_{out}$ | $S_{21}$ | $T_{out}$ | $S_{21}$ | $T_{out}$ | $S_{21}$ | $T_{out}$ |
| Jan | 776 | −4.0 | 725 | −2.4 | 775 | −4.0 | 817 | −5.9 | 832 | −5.3 | 815 | −5.3 | 790 | −4.5 | 743 | −3.0 |
| Feb | 728 | −4.8 | 693 | −3.6 | 724 | −4.7 | 754 | −6.4 | 772 | −5.7 | 746 | −5.4 | 736 | −5.1 | 732 | −5.2 |
| Mar | 692 | −1.3 | 681 | −1.0 | 684 | −1.1 | 697 | −2.4 | 724 | −1.5 | 682 | −1.0 | 693 | −1.4 | 654 | −0.1 |
| Apr | 517 | +3.8 | 523 | +3.6 | 503 | +4.2 | 489 | +3.5 | 525 | +4.7 | 474 | +5.2 | 505 | +4.2 | 511 | +4.0 |
| May | 349 | +9.7 | 342 | +10.0 | 308 | +11.1 | 310 | +10.0 | 341 | +11.0 | 294 | +11.5 | 324 | +10.6 | 304 | +11.2 |
| Jun | 200 | +14.4 | 195 | +14.5 | 169 | +15.5 | 178 | +14.3 | 202 | +15.1 | 165 | +15.6 | 185 | +14.9 | 206 | +14.1 |
| Jul | 140 | +16.6 | 132 | +16.8 | 112 | +17.5 | 131 | +16.2 | 152 | +16.9 | 120 | +17.3 | 131 | +16.9 | 117 | +17.2 |
| Aug | 169 | +15.6 | 145 | +16.4 | 140 | +16.5 | 167 | +14.9 | 191 | +15.6 | 157 | +15.9 | 162 | +15.8 | 165 | +15.7 |
| Sep | 309 | +10.7 | 272 | +11.9 | 284 | +11.6 | 317 | +9.7 | 339 | +10.4 | 308 | +10.7 | 305 | +10.8 | 306 | +10.8 |
| Oct | 463 | +6.1 | 430 | +7.3 | 446 | +6.6 | 479 | +4.8 | 502 | +5.6 | 471 | +5.8 | 465 | +6.0 | 471 | +5.8 |
| Nov | 597 | +1.1 | 546 | +2.8 | 586 | +1.5 | 623 | −0.4 | 643 | +0.2 | 620 | +0.3 | 602 | +0.9 | 632 | −0.1 |
| Dec | 715 | −2.1 | 665 | −0.4 | 716 | −2.1 | 757 | −3.9 | 773 | −3.4 | 756 | −3.4 | 730 | −2.6 | 727 | −2.5 |
| Annual avg. | 5656 | +5.5 | 5349 | +6.3 | 5448 | +6.0 | 5718 | +4.5 | 5994 | +5.3 | 5609 | +5.6 | 5629 | +5.6 | 5568 | +5.7 |

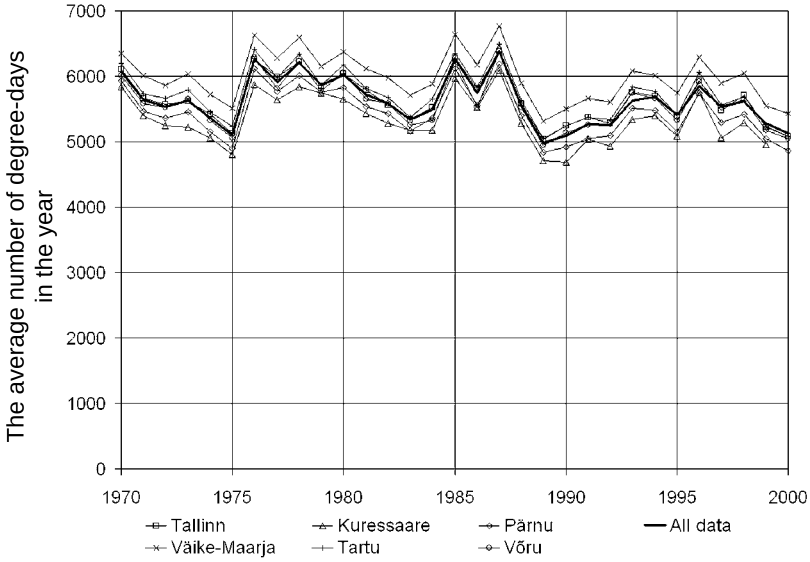



**Fig. 9.** The average numbers of heating degree-days $S_{21}$ in different years.

## 6. DISCUSSION

To guarantee the maximum frequency and sequence of the test reference year, it contains months from a number of different years. Using months from different years requires climatic data at the beginning and at the end of the month to be smoothed. Strictly speaking, the smoothing period (sixteen hours per month) does not represent physical data. To avoid this, one actual year may be used. Comparing annual average $FS$ statistics of the test reference year $(\overline{FS} = 0.05)$ and of the year 1991 $(\overline{FS} = 0.08)$ and the heating degree-days and cumulative distributions of climate parameters of these years, we see that the year 1991 is not so close to the long-term data as the test reference year. The deviation in temperature and heating degree-days is significant. This shows that the selection procedure, used to construct the test reference year, is acceptable. Therefore it is suggested that the selected test reference year, containing months from a number of different years, should be used for energy calculations.

The test reference year was selected from the Tartu meteorological station, because only at this selected station radiation data were directly measured. There are methods available to assess solar radiation on the basis of cloud and sunshine duration [27,28]. Nevertheless, the results of these empirical equations are approximate and give rough estimates of solar radiation [26]. Therefore, using these approximate methods to calculate solar radiation may result in a greater margin of error than using the test reference year solar data from Tartu for the whole of Estonia.

Temperature as the main climatic parameter for heating energy demand and humidity data were used from all six weather stations. Heating degree-day analysis shows that the deviation of the data of these meteorological stations from the average of all data is almost the same as the deviation during different years at one meteorological station and that these deviations are below ±9%. This shows that it is reasonable to use one test reference year for all locations in Estonia.

Different weighting factors for the main climatic parameters have been used in different test reference year studies. They were not used in this study where all the parameters have the same weight. Naturally, each climatic parameter has a different influence on the energy demand. However, one could not say that one parameter, e.g. temperature, is more important than humidity or solar radiation. Humidity does not affect heat demand but affects the cooling coil capacity greatly. Temperature and solar radiation affect both heating and cooling demand. Additionally, the influence of these climatic parameters also depends on the type of building and on the purpose for which the climatic data are used. For example, the influence of solar radiation on cooling and heat demand is different for an office building with a glass facade that is completely exposed than it is for a detached house with a relatively small glazed area and solar protection from the neighbourhood. However, the test reference year should not be building-specific, it should be a good compromise for all cases. The problem of weighting factors will be a subject of further studies.

## 7. CONCLUSIONS

The test reference year for energy calculations and simulations for Estonia has been constructed. To guarantee maximal probable frequencies, sequences, and correlation between the main climatic parameters, the test reference year contains months from a number of calendar years. The file of TRY is downloadable from the homepage of the Estonian Meteorological and Hydrological Institute: http://www.emhi.ee.

The test reference year may be used for many applications, such as energy performance of buildings, simulation of active or passive solar energy systems, HVAC system performance and indoor climate analysis. At the same time, one should notice that the test reference year, representing a typical year, has limitations that should be taken into account in hygrothermal calculations and system planning.

For simple estimation of the annual heating demand, the average number of heating degree-days was calculated from long-term data for six locations.

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## Eesti energiaarvutuste testaasta

Targo Kalamees ja Jarek Kurnitski

On analüüsitud Eesti kliimat ja konstrueeritud testaasta kütte ja jahutuse energiakulu arvutuseks. Testaasta valikul on kasutatud kuue linna – Tallinna, Tartu, Pärnu, Kuressaare, Väike-Maarja ja Võru – 31 aasta (1970–2000) kliimaandmeid. Testaasta koosneb kaheteistkümnest tüüpilisest kuust, mis on valitud erinevatest aastatest õhutemperatuuri, õhuniiskuse, päikesekiirguse ja tuulekiiruse põhjal. Lihtsamateks kütteenergia arvutusteks on välja toodud kuue linna 31 aasta ja kuude keskmised kraadpäevade arvud.