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METHODS FOR COMPENSATE LACK OF CLIMATE BOUNDARY DATA

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Abstract

Laws and regulations require that energy needs, indoor climate and moisture safety should be estimated and analyzed during the design phase, before a house is built. Available tools to predict the hygrothermal conditions need, in general, hourly exterior and interior climate boundary conditions. Available climate data sometimes consist of periods with incomplete or lack of data.

The aim or this paper is to present methods in order to supplement periods with lack of data and methods in order to create diffuse, direct and long wave radiation. Presented methods to supplement and create climate data was tested in a case study in a wood frame roof.

The importance of using reliable climate boundary conditions in order to estimate the hygrothermal conditions before a house was build is presented. It is shown that real climate boundary conditions need to be used to reach correlation between measured and calculated hygrothermal conditions. The need for reliable climate boundary conditions for dimensional purposes and that WUFI 5.2 can be used in a reliable manner when calculating hygrothermal conditions in wood frame roofs located in Northern European climate are shown.

1 INTRODUCTION

1.1 Background

New laws and regulations during the last years require that energy need, indoor climate conditions and moisture safety should be estimated and analyzed during the design phase, before a house is build [1]. Today there are several energy, heat- and moisture calculation tools that are used in order to fulfil the requirements by estimating needed factors in the design phase, such as IDA ICE, VIP-Energy, DEROB, WUFI, DELPHIN, HAM-tools etc. [2, 3, 4].

In general, the calculation tools calculate hourly values for energy need, indoor climate conditions or heat- and moisture transport using numerical solutions. In order to obtain reliable results hourly climate boundary conditions are needed as input since climate conditions varies over time, sometimes with high variations between different hours [2, 3]. Most energy, heat- and moisture calculation tools include default climate boundary conditions to be used in the evaluation process. These exterior default climate boundary conditions, in one way or another, are mainly based on hourly climate measurements carried out by national metrological and hydrological institutes [5, 6, 7]. Hourly values are needed in order to determinate dimensional effects, such as highest energy effect need for heating or highest temporary moisture load.

The content of default exterior climate boundary conditions varies between different calculation tools and between different climate files. In some cases real exterior climate data from one single year can be used. In other cases some kind of mean climate was created based on real climate conditions from several years [4, 6, 7]. Exterior climate data can also be created using software climate tools [8]. Interior hourly climate boundary conditions can be created using standards based on used exterior climate data [9, 10] or dependent on limits for required indoor climate conditions [1, 6]. Measured or created climate data for specific projects, can be used as climate boundary conditions [6, 7, 3, 11].

Working with measured climate data from Swedish meteorological and hydrological institute, SMHI, or own measured interior or exterior climate data to be used as boundary climate data conditions in specific projects it was found that almost all measurements include periods with impaired or lack of data. Periods with lack of data depends on measurement problems and varies in length from single hours to longer periods up to months. Some cases lack measured short- and long wave radiation. In order to get complete climate boundary conditions when there are periods with lack of data, there is a need to develop methods to compensate for this lack of data.

1.2 Aim

The purpose of this paper is to present a method that can be used in order to compensate for periods with lack of climate data. The paper also aims to present methods that could be used in order to create climate data for direct and diffuse short wave radiation and long wave radiation.

The intention is further to compare measured and calculated temperature and relative humidity (RH), in a case study, where calculated values were carried out using real but inadequate climate boundary data that had been supplemented and radiation climate data that have been created using presented methods.

1.3 Limitations

This paper does not consider any material properties or material boundary conditions. The paper focus on coupled heat- and moisture transport in wood frame constructions, i.e. the methods for compensating lack of climate data were tested in a wood frame roof. The calculation model is only briefly described and a detailed description is found in separate reports [11, 12].

2 METHODS

The methods are divided in three parts; methods for supplementing periods with lack of climate data, a method for creating long- and a method for creating shortwave radiation.

Hygrothermal test calculations was then carried out using default boundary climate conditions [13] and real supplemented climate data [11, 12] with and without created long- and shortwave radiation. The calculations were carried out in a roof using the hygrothermal calculation tool WUFI 5.2. Calculated temperature and RH were then compared to measured values in studied position. Comparisons between measured and calculated values were made using the Folos 2D visual mold chart [14]. Periods when mold growth becomes possible was based on LIM I [15].

2.1 Methods supplementing lack of in- and outdoor climate boundary conditions

The methods for supplementing periods with impaired or lack of climate data were simple and varied depending on climate parameters and the length of periods with lack of data. Primarily, if other reliable climate data was available at the same time when lacks of data occurred this data was used as supplement for the lack of data. If no other reliable climate data was available, shorter periods less than one week with lack of hourly exterior temperature, RH and radiation climate boundary data were supplemented with the previous day hourly climate data value. The last daily temperature and RH data were repeated up to seven days. Longer periods than one week with lack of hourly climate boundary data were supplemented with hourly climate data from the same hour and day previous year.

2.2 Method inventing diffuse- and direct solar radiation

The presented method calculates diffuse radiation based on known global radiation in a simple way. Diffuse solar radiation was estimated as a function of the global radiation. With a high amount of global radiation, Wh/m^2, the method estimated that a low percentage of the global radiation consists of diffuse radiation. The lower the amount of global radiation, Wh/m^2, the method estimates that a higher percentage of the global radiation consists of diffuse radiation. During nights without global radiation, i.e. global radiation < 2 Wh/m^2, the diffuse radiation was 0 Wh/m^2. The percentage of global radiation that assumes to consist of diffuse radiation changes stepwise between different amounts of global radiation as shown in Table 1.

The method was based on experience from measured global- and diffuse radiation in the Swedish city Växjö during 1996. The choice of period and city depends on the problem to find a period and location when measured diffuse and global radiations were available at the same time. The relationship between measured global and diffuse solar radiation and estimated diffuse solar radiation based on measured global solar radiation for Växjö 1996 were presented in Figure 1.

Table 1: Estimated diffuse radiation based on a percentage on the amount of global radiation.

Global rad. (Wh/m^2)	% diffuse of global rad. (%)	Diffuse rad. (Wh/m^2)
0 – 1.9	0	0
2 – 99.9	100	2 – 99.9
100 – 119.9	99	99 – 118.7
120 – 159.9	88	105.6 – 140.7
160 – 199.9	77	123 – 154.9
200 – 299.9	66	132 – 198.9
300 – 399.9	55	165 – 220.9
400 – 499.9	44	176 – 220.9
500 – 699.9	33	165 – 231.9
700 –	22	154

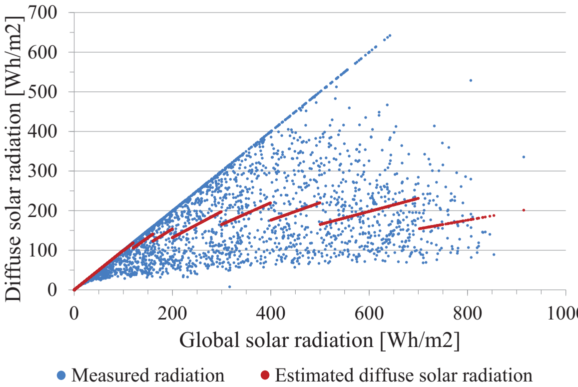


Figure 1: Relationship between measured global and diffuse solar radiation from the Swedish city Växjö 1996 and estimated diffuse solar radiation using the radiation and percentages in table 1.

2.3 Method for creating long wave radiation - Clearness index method

Presented method was called the clearness index method and is a relatively simple method for calculating the long wave radiation from the sky. The long wave radiation from the sky (L_w) is typically measured in W/m^2 or Wh/m^{2}h. The measuring instrument is some kind of pyrgeometer, e.g. a Hukseflux IR02 [16]. To make it clear that this radiation does not originate from the sun it is sometimes called the atmospheric long wave radiation. The long wave radiation is of the order

200-400 W/m^2 [17, 18] and varies on a daily and seasonal basis. The long wave radiation is seldom measured and must therefore be estimated based on other parameters. The most important parameters are the outdoor temperature, the RH and the cloudiness of the sky [19]. Many formulas exist and only a brief description of the chosen methods and formulas will be given. When formulating algorithms based on other meteorological data it is natural to start with Stefan-Boltzmann equation for the thermal radiation from a surface with the temperature T (K):

$$L_w = \varepsilon \cdot \sigma \cdot T^4 \qquad (1)$$

where ε is the emissivity of the surface and σ is the Stefan-Boltzmann constant. Many authors have formulated algorithms for L_w mainly based on:

- The outdoor temperature: T_o (K)
- The moisture content in air described by : outdoor vapor pressure p_o (kPa) or dewpond T_d (K) or perceptible water w (mm)
- Some kind of cloudiness index: c_l (-)
- The atmospheric pressure at the ground (more seldom).

Presented method is based on the formula above (1). The outdoor temperature is used with an estimation of the sky emissivity. The emissivity is calculated from hourly values of outdoor and dew point temperature together with a 24 hours average calculated clearness index of the sky:

$$\varepsilon_{sky} = 1.5357 + 0.5981\left(\frac{Td}{100}\right) - 0.5687\left(\frac{T_o}{273.15}\right) - 0.2799\,K_0 \qquad (2)$$

$$L_w = \varepsilon_{sky} \cdot \sigma \cdot {T_o}^4 \qquad (3)$$

Parameters were estimated from 9 years hourly data from four Swedish cities [19]. Clearness index K_0 (-) was defined as quota between measured global solar radiation on a horizontal surface on ground I_G (Wh/m^{2}h) and extra-terrestrial solar radiation H_0 calculated over 24h average data.

$$K_0 = \frac{I_G}{H_0} \qquad (4)$$

H_0 is the daily average extraterrestrial radiation in (Wh/m^{2}h) [20]:

$$H_0 = \frac{I_{SC}}{\pi} \cdot \left[1 + 0.033\cos\left(2\pi\frac{d_{nr}}{365}\right)\right] \times (\cos(\varphi)\cos(\delta)\sin(\omega_s) + \omega_s\sin(\varphi)\sin(\delta)) \qquad (5)$$

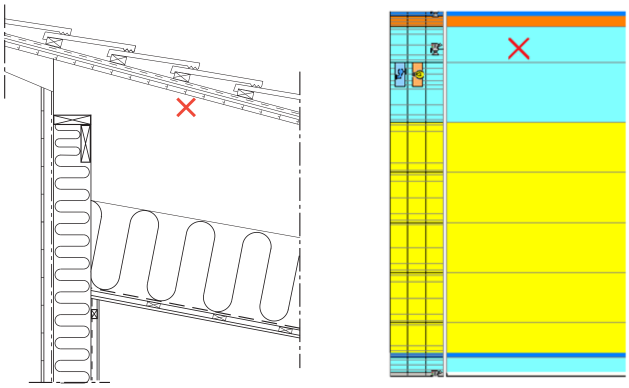
where φ (rad) is the latitude, δ (rad) is the solar declination, ω_s (rad) is the sunset hour angle, I_{SC} is the solar constant (1367 Wh/m^{2}h) and d_{nr} is the day number (1-365).

$$\delta = 0.4093 \cdot \sin\left(2\pi\frac{284 + d_{nr}}{365}\right) \qquad (6)$$

$$\omega_s = \cos^{-1}(-\tan(\varphi)\tan(\delta)) \qquad (7)$$

3 MATERIALS – CASE STUDY TEST

Hygrothermal calculations with default and real supplemented exterior climate and different climate radiation models and comparisons to measured values were carried out in a wood framed roof construction. Studied position was located on the inside of the tongued and grooved wood in a 500 mm wide cold attic space. The house is a single family house located in the Swedish municipality Upplands-Bro 40 km west of Stockholm. A brief description of the cold attic with studied position and used calculation model [11, 12] are presented in Figure 2.



Roof from the outside:
Tiles, part of the outer Sd value
1 mm PVC roof membrane, Sd = 15 m
22 mm Massive wood – Spruce radial
70 mm Air gap
50 mm Air gap
70 mm Air gap
460 mm Mineral insulation, λ = 0,037 W/mK, including roof beams
1 mm Vapor retarder, SD = 50 m
30 mm Air gap, no ACH
13 mm Gypsum board

Figure 2: Drawing and WUFI calculation model showing the studied position [11, 12].

4 RESULTS

Five different cases with calculated temperature and RH were compared to measured values. The results from each case were analysed and also compared with each other in Folos 2D visual mold chart. Vertical lines on the top indicate a short period with replaced climate boundary data and horizontal lines indicates longer periods with lack of climate boundary data [11]. Specific replaced climate boundary condition for each hour was presented by in a separate report [12].

Figure 3 presents a comparison between measured and calculated temperature and RH using default climate boundary conditions [10]. The cases are: with and without explicit long wave radiation balance in WUFI 5.2.

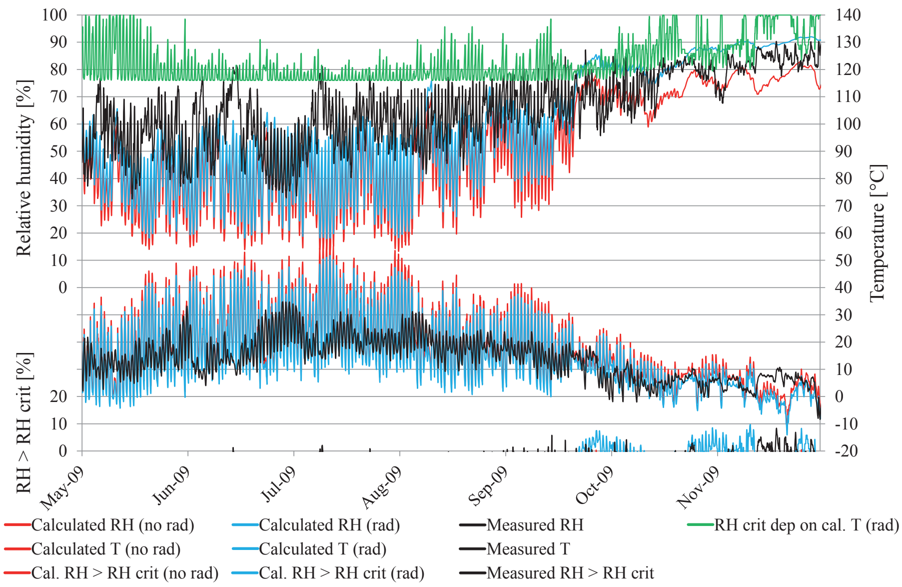


Figure 3: Comparisons between measured (black) and calculated temperature and RH using default climate boundary conditions and with (turquoise) and without (red) explicit long wave radiation balance in WUFI 5.2. RH_{crit} (green) dependent on calculated temperature including explicit long wave radiation.

Figure 4 presents a comparison between measured and calculated temperature and RH using real, but supplementary, climate boundary conditions and invented diffuse solar radiation. The cases were: with and without explicit long wave radiation balance in WUFI 5.2.

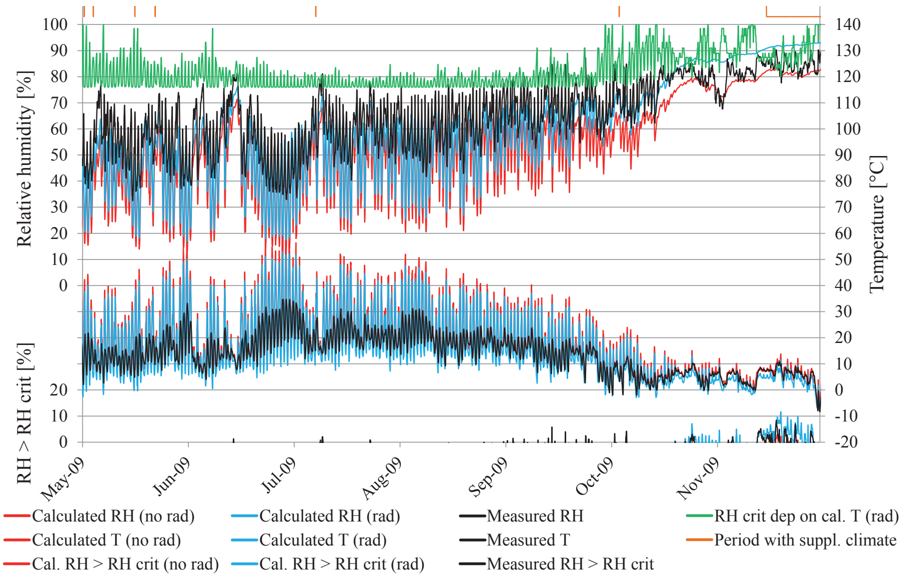


Figure 4: Comparisons between measured (black) and calculated temperature and RH using real, but supplementary, climate boundary conditions and invented diffuse solar radiation and with (turquoise) and without (red) explicit long wave radiation balance in WUFI 5.2. RH_{crit} (green) dependent on calculated temperature including explicit long wave radiation.

Figure 5 presents a comparison between measured and calculated temperature and RH using real, but supplementary, climate boundary conditions and invented diffuse solar radiation with above presented Clearness Index radiation method (CI rad) calculating long wave radiation.

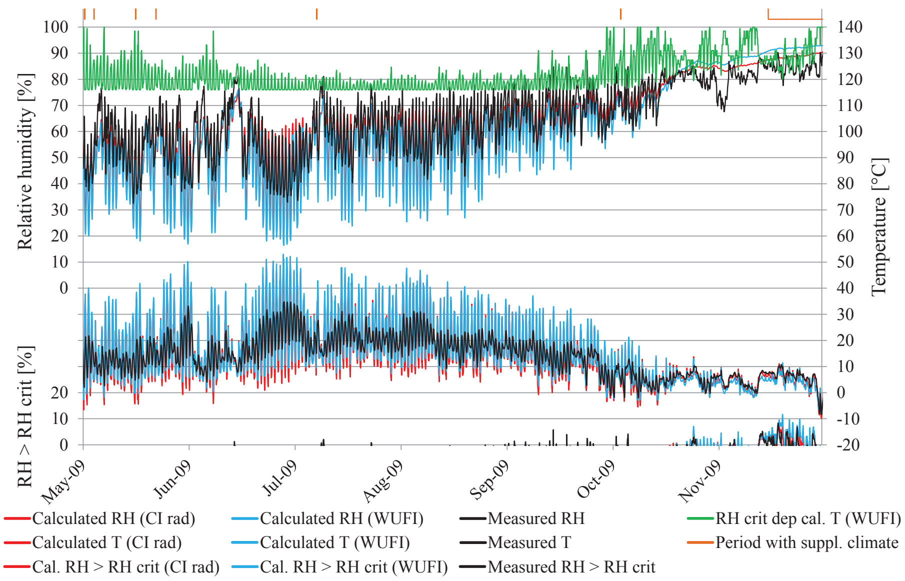


Figure 5: Comparisons between measured (black) and calculated temperature and RH using real, but supplementary, climate boundary conditions and invented diffuse solar radiation and using WUFI 5.2 explicit radiation balance (turquoise) and invented long wave radiation, CI rad, method (red). RH_{crit} (green) dependent on calculated temperature for WUFI 5.2 explicit radiation balance.

5 ANALYSIS AND DISCUSSION

As expected, calculated values using WUFI 5.2 default climate boundary conditions do not correlate to measured values, as shown in figure 3. Although there are clear deviations between measured and calculated values in June and July, as shown in figure 3, greater deviation between measured and calculated values were expected. This since previous research shows higher differences between different years [3, 11]. Other studies show that the Swedish default boundary conditions in WUFI 5.2 seems to report a lower risk of mold growth compare to real climate conditions [21]. The results show a slightly higher amount of risk using WUFI 5.2 default climate boundary conditions compare to measured values. The reason could be that the 2009 exterior climate creates a lower risk of mold growth compared to other years, such as 2011 [11].

In general there was a good correlation between the measured and calculated values when real, but supplemented, climate boundary conditions were used and long wave radiation was included in the calculations, as shown in figure 4 and 5. Detailed analysis indicates that shorter periods with supplemented climate boundary conditions do not highly influence the results. However, previous studies indicate that longer periods of replaced temperature and relative humidity, which highly affect the calculations results compare to other climate parameters, influence the correlation between calculated and real measured values [11].

As expected, calculated values using long wave radiation show higher relative humidity caused by a lower temperature and further on a higher risk of mold growth, as shown in figure 3 and 4. The correlations in length and amount of critical conditions comparing measured and calculated values, including long wave radiation, as shown in figure 4 and 5, show that long wave radiation should be taken into account in the calculations in order to predict the risk of mold and moisture related damages. The correlation between measured and calculated values, using two different methods for creating long wave radiation, as shown in figure 5, indicate that the clearness index method creates slightly higher RH in studied position during the winter.

All calculations show higher amplitude in temperature and relative humidity in calculated values compare to measured values. The higher amplitude in relative humidity probably depends on the variations in calculated temperature, probably caused since tiles, and its heat capacity, do not become included in the exterior roof assembly in the calculation model.

6 CONCLUSIONS

The results show that WUFI 5.2 could be used in order to make reliable hygrothermal calculations of the climate in attics in wood framed roofs in northern European climates. Real climate boundary conditions must be used in order to reach correlation to measured values. The results indicate that mean climate conditions not could be used without further analysis for dimensional purposes.

Used methods in order to supplement periods with lack of climate data and to create diffuse, direct and long wave radiation were successfully used in order to create climate boundary conditions to be used in the calculations. Long wave radiation has to be included in the climate boundary conditions in the calculations in order to obtain reliable results. Both the Clearness index method and WUFI 5.2 method inventing long wave radiation works in the context.

For both the reconstruction of diffuse and long wave radiation to hourly values the “true” values can never be achieved since the measured data do not have enough information. One can only create reasonable climate files with these methods. The choice of method should also be dependent of how these climate files would be used, i.e. if the aim is calculating a good average value or if the aim is to simulate worst case scenarios.

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