DEVELOPMENT OF HYGROTHERMAL REFERENCE YEARS FOR GERMANY

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ABSTRACT

For a safe design of new buildings or for the assessment of damages in existing buildings a representative exterior climate is necessary. Especially for constructions which react sensitively on the amount of driving rain an assessment with thermal reference years e.g. Test Reference Years (TRY) is not suitable (Christoffer et.al, 2004).

Within the official research cluster energy efficient buildings (ENOB) the Fraunhofer Institute for Building Physics (IBP) developed new Hygrothermal Reference Years (HRY) for Germany including all required climate elements for hygrothermal simulations. The validation of the new reference years were carried out by comparing the hygrothermal behavior of building components simulated with both: the new HRY and real measured data over several years.

INTRODUCTION

The increasing demand for saving energy needs innovative solutions for the building sector. This leads to a reduction of the energy losses in general and requires a decrease of the transmission and infiltration losses in particular.

According to the German DIN 4108 the minimal thermal resistance (R-value) of exterior components rose from 0.39 m²K/W in 1952 to 1.2 m²K/W in 2001. In parallel wind and air tightness of the assemblies has been improved. The German decree for energy saving (ENEV) requires an air change rate (n_{50}) of $n_{50} = 1.5\ h^{-1}$ for buildings with a ventilation system. An energy efficient passive house requires even lower air change rates of $n_{50} \leq 0.6\ h^{-1}$. Wind tightness from outside and high insulation levels reduce the drying potential of building components, while air infiltration and vapor diffusion from inside increase the moisture level. Therefore it is necessary to assure that the moisture balance of such a construction is still in the equilibrium state and remains below the critical levels for moisture sensitive materials. This can be assured by means of hygrothermal simulations considering all influencing factors.

For a holistic hygrothermal assessment of such a component, realistic reference climate data is necessary. There are approaches to model a typical indoor climate for Central European conditions e.g. in the EN 15026:2007 depending on the outdoor climate. This procedure even increases the importance of a reliable outdoor climate dataset. For thermal purposes the ISO 15927-4:2005 describes a method to create typical meteorological years based on a so called Finkelstein-Schafer (FS) statistic (Finkelstein et.al., 1971). This approach was inter alia used for the preparation of thermal reference years for Finland (Kalamees et.al., 2011). Nevertheless the ISO 15927-4:2005 refers to the use of other methodologies for the generation of reference years with a different aim of assessment. For instance the German Meteorological Service (DWD) uses a typical sequence of the macroscopic weather situation for the preparation of their Test Reference Years (TRY), which are also focused on the thermal assessment of a construction (Christoffer et.al, 2004).

CLIMATE DATA

For the generation of the HRY, which should be suitable for the hygrothermal assessment of a construction, measured data for 17 stations from the Meteomedia AG are used. To be suitable for hygric purposes the new HRY have to contain rain data either. In order to create consistent climate data the selection of the months for the HRY should be based on temperature and on rain data. The evaluated time period was from 2003 – 2010. 15 stations, which are located nearby the reference stations of the TRY from the DWD and two additional control stations in Oschatz and Baden–Baden are investigated. The position of each station is shown in Figure 1.

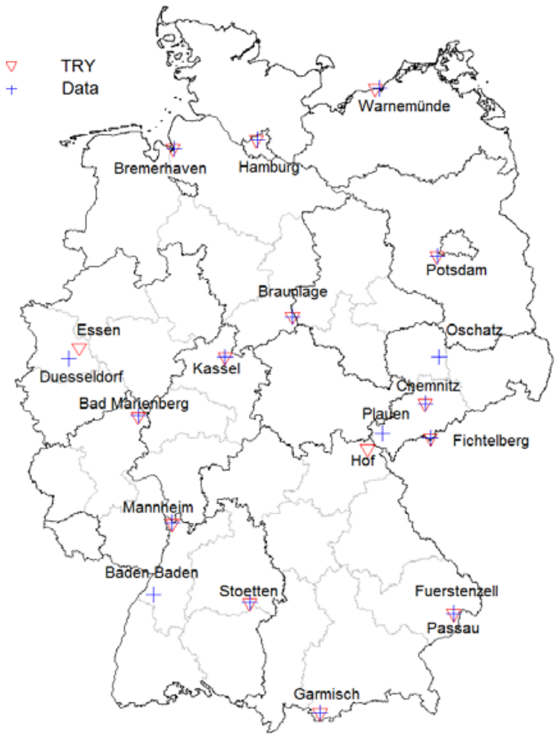

Figure 1: Location of the investigated stations and the DWD TRY reference stations

The figure illustrates that the stations for the HRY are near the reference stations for the TRY. The idea was the use of the zonal classification of the TRY also for the new generated HRY´s. The zonal classification for the TRY is based on the cluster analysis of 253 weather stations (Blümel et.al., 1986). A new cluster analysis based on 17 stations was therefore neither reasonable nor necessary. The data from Meteomedia must be adjusted for hygrothermal purposes. In the measured data the atmospheric counterradiation was missing. During the daytime atmospheric counterradiation (ILAH) was calculated out of clearness index (CI) in accordance to (Perez et.al. ,1992). With an empirical model validated for Holzkirchen the ILAH was calculated out of the CI. During the nighttime the CI was interpolated and the ILAH was calculated depending on these interpolated CI. The limiting values for the ILAH are in accordance to the TRY manual (Christoffer et.al, 2004) for a cloudless and a clouded hemisphere. The ILAH is necessary for the explicit radiation balance in the simulation. The explicit radiation balance in accordance to (Kehrer et.al., 2006) considers the long wave radiation exchange of a surface. The relative humidity was calculated from the dew point temperature based on (Christoffer et.al, 2004). To simplify the simulation leap years are removed.

METHODOLOGY

The cumulative distribution function (CDF) in the FS statistic is one possibility for describing data. Other possibilities are descriptive statistic indexes such as the median, mean, minimum, maximum value, the 25%-, and the 75% quartile. All together, they are known as Box-Whiskers plot (Tukey, 1977). They are used for the selection of the months for the HRY. For the temperature this selection process is visualized in the following Figure 2.

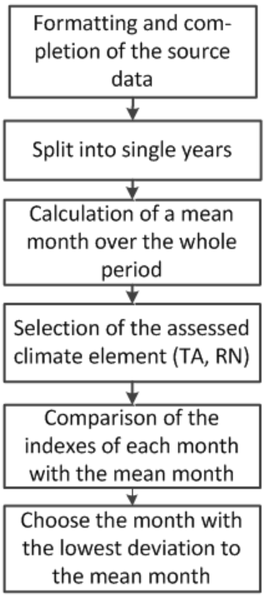

Figure 2: Process of the selection of a mean month

For each month of the period under observation e.g. January 2003 till January 2010, the indexes are calculated and compared to the indexes of the mean month. For each index the modulus of the difference is ranked and the one with the smallest deviation to the mean month is chosen. This process is repeated for each index and for the two assessed climate elements temperature and normal rain. Next the number of occurrences of each single month in the indexes is summarized. The month, which appears most frequently, is chosen. For this month the indexes are in the best accordance to a mean month. For the HRY mostly months from different years are sequenced. For the station Braunlage on example the chosen months are listed in Table 1.

Table 1: Chosen months for the HRY at Braunlage station

HRY January	January 2003
HRY February	February 2009
HRY March	March 2004
HRY April	April 2004
HRY May	May 2009
HRY June	June 2008
HRY July	July 2003
HRY August	August 2007
HRY September	September 2004
HRY October	October 2008
HRY November	November 2008
HRY December	December 2004

The table shows that most of the monthly intersections are between different years. To avoid unrealistic leaps between the months, the crossovers are smoothed in accordance to (Blümel et.al., 1986). In Figure 3 this is visualized for the temperature at the intersection between January 2003 and February 2009.

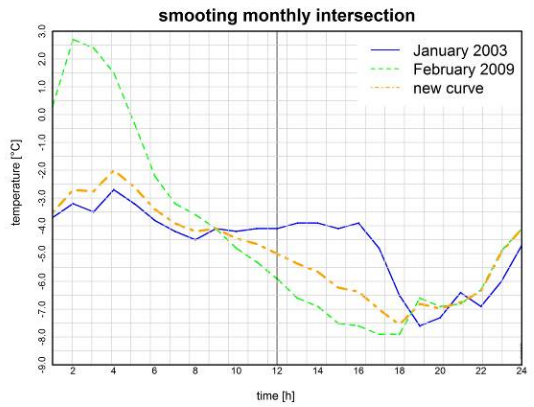

Figure 3: Smoothing of a monthly intersection

If a HRY is used to simulate a period longer than one year it is necessary to string HRY´s together. To prevent an intersection between the December of the first HRY and the January of the second HRY it is reasonable to smooth this intersection too. For this purpose there was a linear interpolation between 12:00 of 31th of December and 12:00 of 1st of January.

SIMULATION

For the evaluation of the new generated HRY`s, hygrothermal component simulations were carried out. In the first step the HRY´s are compared with the measured weather data, based on the resulting water content of the critical layer of sensitive constructions. The constructions are chosen due to their sensitivity on the fluctuation of the different climate parameters. In detail the considered constructions are:

1. *A north oriented steep roof with a metal sheeting*
2. *A flat roof with a white roofing membrane*
3. *A green roof*
4. *A west oriented masonry wall with interior insulation*

The layers of each construction are listed in Table 2 from outside to inside. The steep roof has an inclination of 50°. The boundary conditions of the green roof are in accordance to (Schafaczek et.al, 2013). For central Europe, the west orientation is normally the direction with the highest amount of driving rain. On the other side the north orientation is the direction with the lowest amount of global radiation (ISGH).

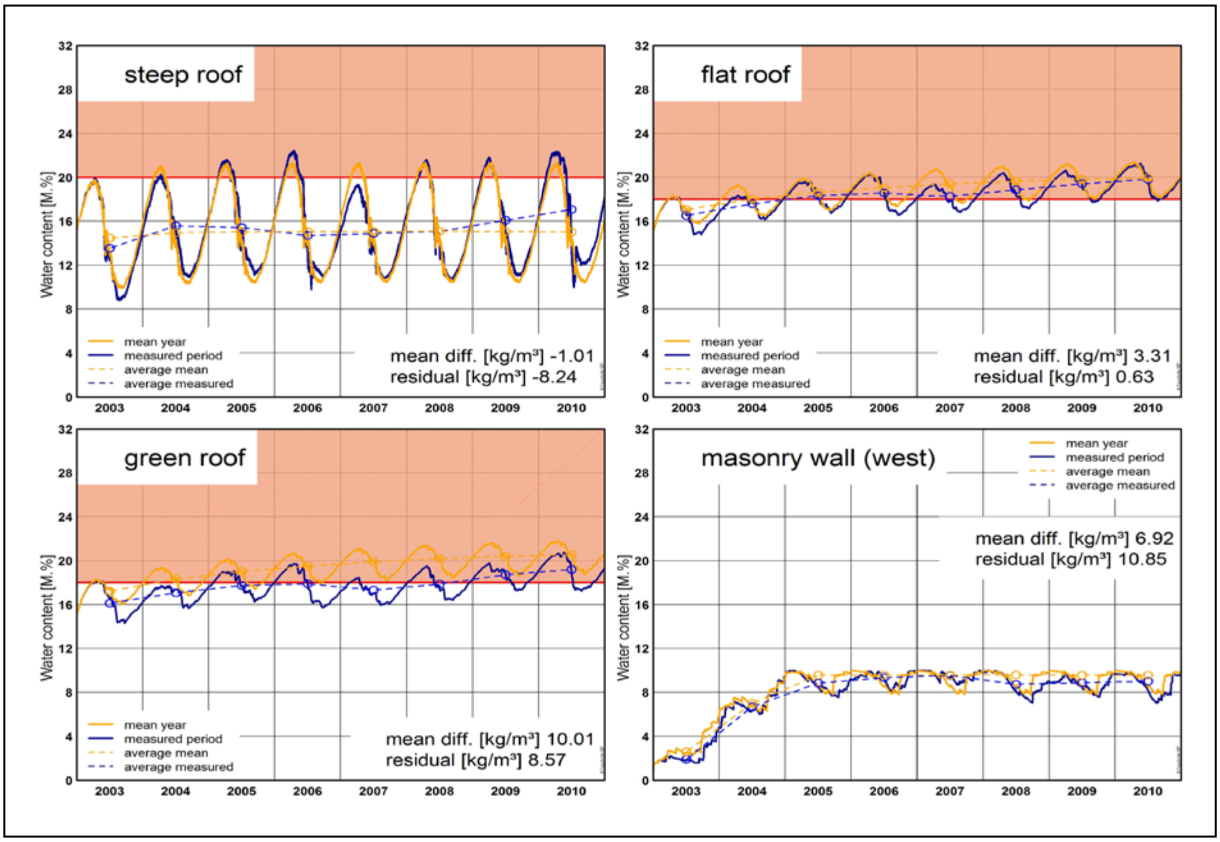

Figure 4: Comparison of the simulated water content in the critical layer for the four considered constructions. The red area is the critical water content for the degeneration of wood according to the DIN 68800.

Table 2:
Build-up of the considered sensitive constructions from outside to inside

Nr.1	Nr.2	Nr.3	Nr.4
Softwood	OSB	Generic Substrate	Lime cement plaster
Mineral wool	Mineral wool	Vapor retarder (s_d-value 100m)	Masonry wall
Vapor retarder (s_d-value 2m)	Vapor retarder (s_d-value variable)	OSB	EPS
		Mineral wool	
		Vapor retarder (s_d-value variable)	
Gypsum-board	MDF board	MDF board	Gypsum plaster

The indoor climate was assumed as constant with 20°C and 50% RH. This leads to a higher indoor moisture load during winter than the climate model according to EN 15026. The masonry wall and the green roof are very sensitive for the amount of rain. The steep and the flat roof are sensitive to the ISGH and the atmospheric counterradiation. For all four constructions the ambient temperature has a big influence. The hygrothermal component simulation is carried out with the hygrothermal component simulation model WUFI® (Künzel, 1995). Each of the assessed constructions has a critical layer which, in accordance to the experience, fails first. For the steep, the flat, and the green roof this is the exterior wooden sheathing or the oriented strand board (OSB). For the west oriented wall the brickwork is the critical layer. The critical layers are underlined in Table 2. For the station Braunlage the resulting water content of these layers are shown in Figure 4. The dashed lines in Figure 4 are the annual means, the continuous curves are the hourly simulation results. The blue curves are based on measured data and the orange ones are based on the HRY. The mean difference value is the arithmetic mean of the differences over the eight years period. The residual difference is the remaining difference at the last time step of the simulated result data. A positive difference indicates that the HRY leads to higher water contents. For the example in Figure 4, apart from the steep roof, the HRY produces slightly higher water contents than the measured one. For the steep roof some measured years are more critical than the HRY. In order to cover that, an additional approach is presented in the chapter *Cold Years*. However the steep roof will fail after one and a half years based on both climate sources, so the assessment of the construction will be the same. This simulation procedure was carried out for all stations.

Reference Zones

The aim of the project was the creation of HRY`s for whole Germany. This could be done via the zonal classification of the TRY from the DWD. For the TRY the DWD created zones with a similar ambient climate. The zonal classification was carried out with a statistical factor analysis (Christoffer et.al, 2004). Because of the similar component behavior under comparable ambient climate conditions it is possible to reduce the number of zones for the HRY. This reduction process is carried out in a two steps approach. In the first step a correlation matrix for the assessed climate elements over all stations was generated. The assessed climate elements are the temperature, the global radiation, and the vapour pressure. According to a sensitivity analysis these parameters have the highest influence on the resulting water content of the assessed component.

Next the stations are grouped corresponding to the correlation level. The correlation level is adjusted till the assignment of a station is explicit for one climate element. If a group was established for all three assessed climate elements the second step, a hygrothermal component simulation is carried out. The groups, based on the correlation level are only a first rough comparison. The more important criteria is the hygrothermal component behavior. Thereby the four constructions mentioned earlier are compared for all stations within a group. If there is one station that is the most critical one for all four constructions it is the reference station for the whole region. If this is not the case the best candidate station is adjusted e.g. by adapting the relevant climate elements. The whole process is visualized within following Figure 5.

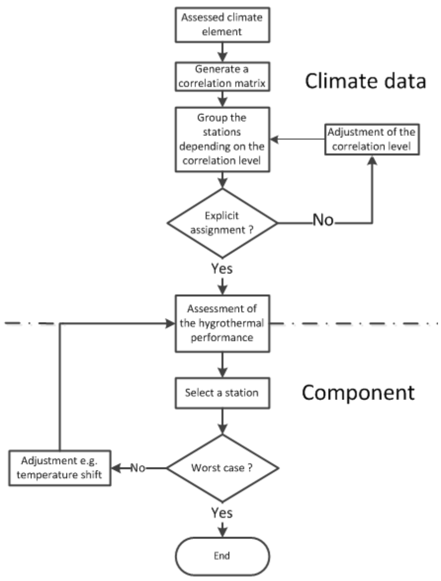

Figure 5: Algorithm for the aggregation of reference zones for the HRY

Following the algorithm mentioned in Figure 5 three groups of stations can be regrouped. The three groups are listed in Table 3.

Table 3:
Groups for the HRY zones

Group 1	Group 2	Group 3
Chemnitz	Braunlage	Bremerhaven
Plauen	Bad Marienberg	Hamburg
(Oschatz)	Kassel	Warnemünde
	Düsseldorf	

The station within brackets is a dummy station for comparison only, which produces lower water contents in the component simulation. The underlined stations are the chosen ones due to the results of the hygrothermal component simulation. Within group two and group three two reference stations are chosen due to the geographical exposition of the assessed region. The courses of the water content are shown for the example of the steep roof from group two in Figure 6.

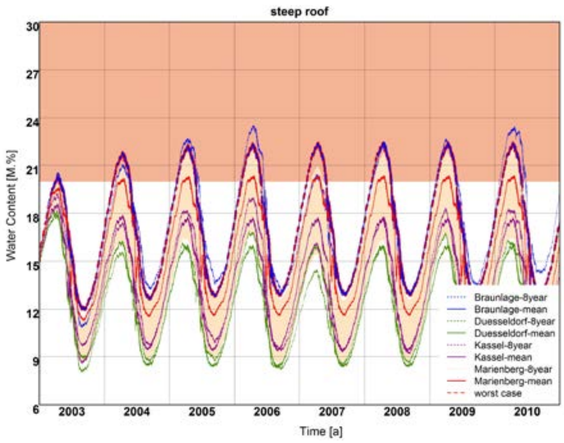

Figure 6: Example of the hygrothermal performance for the steep roof in Group 2

The courses for Braunlage and Bad Marienberg are higher than the ones for Kassel and Düsseldorf. The water content rises above the acceptable water content from the DIN 68800. In other words the construction will fail in Braunlage and Bad Marienberg, while in Kassel and Düsseldorf it will work. Braunlage produces a slightly higher moisture level then Bad Marienberg and the water content course for Kassel is above the one for Düsseldorf. So for group two Braunlage is the reference station for higher regions and Kassel is chosen as reference station for the lower Rhine - Ruhr region.

For the coast group three, the distribution of the driving rain is highly varying between the North and the Baltic Sea region. Hamburg is chosen as the reference station for the North Sea region and Lower Saxony. Warnemünde on the other hand is the reference station for the coast region of the Baltic Sea. Combined with the other locations there are 11 reference stations and zones for the HRY. In Table 4 all stations are listed.

Table 4:
HRY reference station and corresponding TRY zone

HRY Nr.	Corresponding TRY Zone	Station name
1	2	Warnemünde
2	1,3	Hamburg
3	4	Potsdam
4	6,8	Braunlage
5	5,7	Kassel
6	9, 10	Chemnitz
7	11	Fichtelberg
8	12	Mannheim
9	13	Fürstenzell
10	14	Stötten
11	15	Lindenberg

Based on the regional classification of the TRY it is possible to show a regional classification for the HRY`s too. In Figure 7 the regional zones for the German HRY are shown.

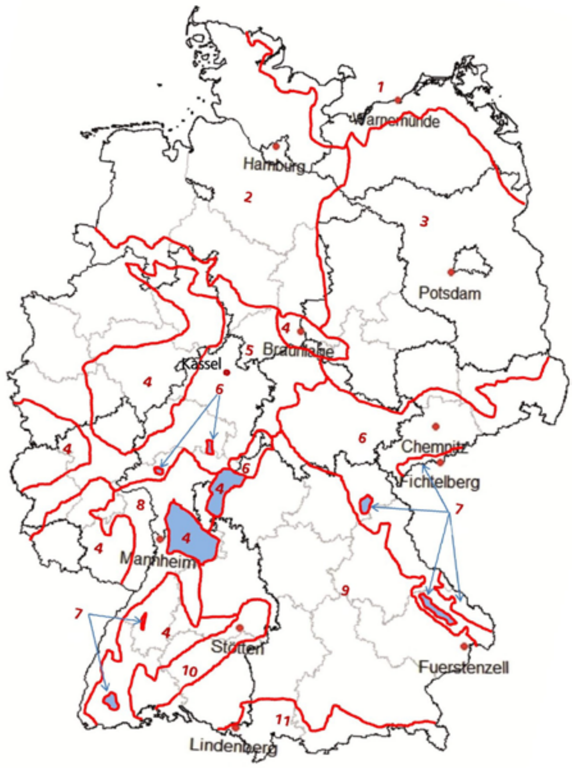

Figure 7: Map for Germany with the regional classification for the HRY`s

Cold Years

As Figure 4 in the validation chapter has shown it is possible that extreme measured years (for example the year 2005) lead to a higher short term water contents then the HRY would predict. For the assessment of a construction this could be a problem.

The European standard for the assessment of components via hygrothermal simulation EN 15026 recommends a temperature shift of -2 K for extreme cold years within a 10 years period. These extreme years are intended to cover such real years. The indoor climate in accordance to the EN 15026 is derived from the ambient climate. This means that the indoor climate varies from station to station. For the cold years assessment the indoor climate from the EN 15026 is used. In Figure 8 these years are labeled as cold HRY. Another aspect is the occurrence of the cold HRY. Depending on the moment the cold HRY occurs, in the period under observation, the effect on the assessment will be different. If e.g. the cold HRY is the last one of the considered period, an unrealistic high end water content will be the result. To investigate this issue, different combinations of cold HRY`s and HRY`s are compared with the measured data. In Figure 8 the courses of the water content for the steep roof in Braunlage are shown. The considered combinations over the eight years period are:

- two cold HRY`s in the beginning to see if the construction reaches the equilibrium state
- eight cold HRY`s as "worst case"
- two cold HRY`s at the end of the period to evaluate the impact on the end water content
- three HRY`s, two cold HRY`s followed by three HRY`s in the end

The last case should give an additional information about the behavior of the construction after an extreme cold period. Figure 8 visualizes the differences between the varying HRY and cold HRY combinations.

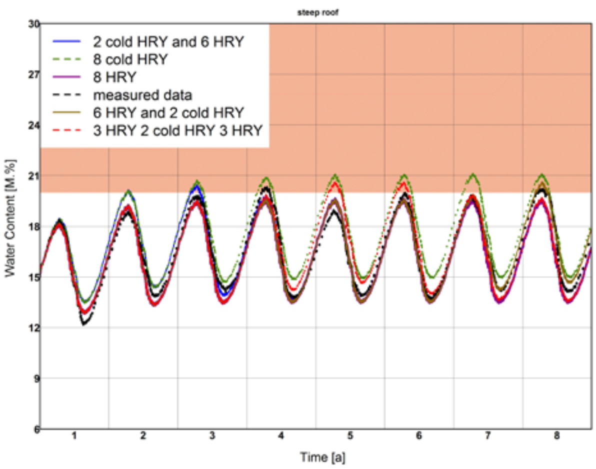

Figure 8: Water courses for different combinations of HRY and cold HRY`s for the steep roof in Braunlage

The red area indicates the critical water content of 20 M.% according to the German standard DIN 68800. The curve based on eight cold HRY shows an unrealistic high moisture level, the construction will fail after one and a half years. The combination of eight normal HRY`s has a lower moisture level then the measured data during the years three, four and eight. The curve based on HRY which starts with two cold HRY reveals, that it takes three years to reach the equilibrium state. Furthermore the water content of the construction shows some hygric inertia. For example the water content of the case with the two cold HRY in the middle reaches its maximum in the fifth and sixth year of the evaluation. But the cold HRY`s are the years four and five which means a hygric inertia of one year for this case. From the perspective of assessment, the construction will fail after four and a half years with the combination of cold and normal HRY and after seven and a half years by using the real measured data.

Even the cold HRY`s are not suitable for the assessment of exposed locations such as mountain areas. Another problem is the consideration of micro climate effects such as the urban heat island effect according to (Oke, 1973). To adjust the HRY`s for such locations and effects a more detailed local climate model is necessary.

Comparison with ISO Standard

Finally a comparison of the HRY with reference years created in accordance to the ISO 15927-4 is performed. The ISO year creation is based on the temperature (TA), the relative humidity (HREL), the global radiation (ISGH) and the wind speed (WS). Briefly the ISO method works as follows: First the CDF, based on the daily means, must be calculated for each month over both the whole period and the current month. In the second step the classification figure (FS) according to (Finkelstein et.al., 1971) is calculated for each of the assessed parameters. Thirdly the FS for the TA, HREL and ISGH are summed. Then the three months with the lowest FS values, which means the minimal deviation from the mean month, are chosen as candidate months. The last step is the selection of the month for the reference year based on the lowest FS of the wind speed of the three candidate months. This approach was used to create reference years for all 15 stations. The comparison of the HRY and the ISO reference years is again based on the hygrothermal performance of the sensitive building components simulated with both climates, using the indoor climate in accordance to EN 15026. In the following Figure 9 the resulting water content of the steep- and the green roof in Braunlage are compared. For the comparison the indoor climate in accordance to the EN 15026 was used.

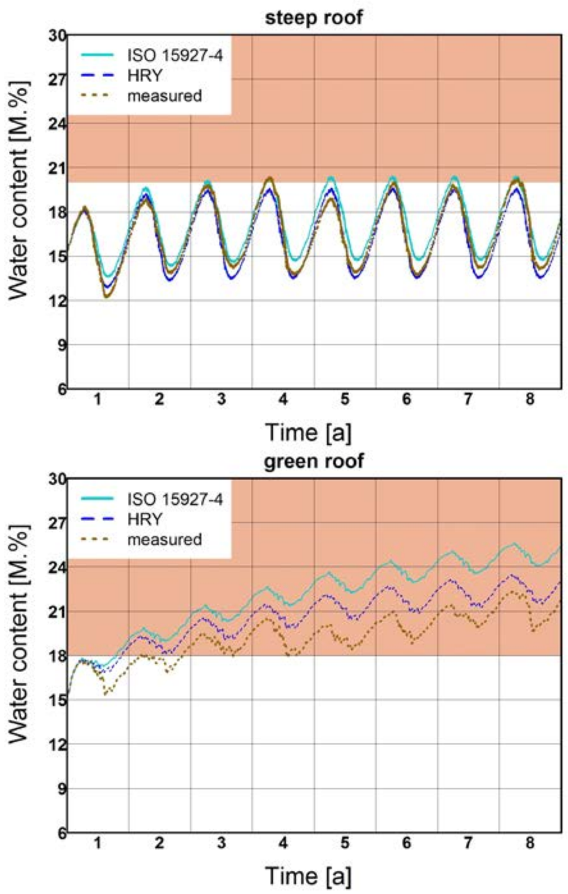

Figure 9: Comparison of the water courses for the steep- and the green roof in Braunlage based on measured data, HRY and ISO reference years.

The brown graph is the resulting water content for the simulation with real measured climate data. The dashed blue one is based on the HRY and the continuous blue one result from the use of the ISO reference year. This procedure was applied to the four assessed constructions at 15 stations.

DISCUSSION OF THE RESULTS

The comparison of simulations with HRY and measured data showed, that the HRY`s are capable for the hygrothermal assessment of components. The usage of HRY`s lead to a critical representative water content. This means that the mean water content based on the HRY is slightly higher than the one based on the measured data. For some constructions an individual measured year could lead to a higher moisture level than a simulation with the normal HRY will predict. For example in Figure 4 the year 2005 is such a year for the steep roof. To prevent a wrong assessment concerning the short term behavior the simulation should be performed until the equilibrium state of the water content is reached. It can be stated that the HRY is capable for the hygrothermal evaluation of constructions in general.

For sporadic extreme years a combination of HRY`s and cold HRY`s as discussed in the chapter *Cold Years* is sufficient.

In order to consider such situations, cold HRY´s in accordance to EN 15026 are created and combined with the normal HRY`s into an eight years evaluation period. If the time of exceeding of the critical water content is compared for the four sensitive constructions at all stations, the combination of three normal, two cold HRY`s and again three normal HRY`s shows best agreement with the simulations based on real measured climate data. After that the two cold HRY`s simulate an extreme cold period, the moisture level of the construction rises cf. Figure 8. The last three HRY`s exhibit if the construction reaches the equilibrium state again or accumulates the moisture. If the courses are not compared with eight years measured data the two cold HRY`s can be followed by more than tree HRY`s to investigate the drying out potential of the construction.

Another aspect is that the main focus of the HRY is the hygrothermal assessment. The TRY and the ISO 15927-4 are focused on energetic aspects. This leads to the question, how the HRY will perform in an energy assessment. To answer this, the heating degree days, according to the German VDI 4710: Part 2, are calculated for heating temperatures of 15°C and 19.4°C. These heating degree days are compared with the values for the TRY reference stations from the VDI 4710: Part 2. Except for Chemnitz, the HRY`s showed a bit less heating degree days on both temperature levels. For a heating temperature of 15°C the mean relative deviation Δ= -3.8% respectively Δ= -4.6% for 19.4°C. The HRY`s will predict a bit lower energy demand then the TRY`s. For the heating purposes the TRY should be used in order to get results on the save side.
The last step of the evaluation was the comparison of the HRY with reference years in accordance to the ISO 15927-4. Compared to the ISO standard the process for the generation of the HRY is relatively easy. Over all stations, the constructions which are not heavily influenced by the rain, showed a good correlation between the HRY and the ISO reference years. If the rain has a bigger influence, the ISO reference years differs from the measured data as well as from the HRY. For the example of the steep- and the green roof this is visualized in Figure 8. The green roof reacts sensitive on the amount of rain and the ISO reference year produces a circa 3 M. % higher end water content then the HRY. For the steep roof on the other hand the courses of both reference years are nearly equal.

CONCLUSION

This paper describes the development of new reference years for the hygrothermal assessment the so called HRY. The method is based on descriptive

statistical measures for temperature and rain. The consistence of the generated HRY is ensured via the hygrothermal simulation of critical components.
To cover whole Germany with the HRY the zonal classification from the TRY was adjusted.
The validation of these new reference years was carried out with hygrothermal component simulation. For the validation the simulated water content in sensitive assemblies based on real measured data and on the HRY´s is compared. This comparison has shown that the HRY`s lead to a slightly higher moisture level. For an assessment under normal conditions they are critical representative for long term evaluation.
For the consideration short term effects the combination of HRY`s and cold HRY´s according to EN 15026 is proposed.

ACKNOWLEDGMENT

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