LOCAL CLIMATE MODELS FOR HYGROTHERMAL BUILDING COMPONENT SIMULATIONS

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ABSTRACT

In many cases the direct surroundings of a building show a bigger influence on the hygrothermal conditions in a component than the regional climate. Although there are already some models, which adapt for example the temperature of reference climate data to a location in a city considering the heat island effect, other models are required to adjust climate elements like humidity and driving rain as well as short and longwave radiation loads. Furthermore exposures like mountains or near waters should be considered. Therefore local climate models have been developed based on measured data in Germany, allowing for simple adaption factors to take into account the local climate influence on the hygrothermal condition in a building component.

INTRODUCTION

Concerning the hygrothermal performance evaluation of building components, the local climate influence can be crucial for certain damage processes like microbial growth or driving rain load. However, often such local climate data are hardly available. Therefore regional reference data or measured data at the nearest station of the target location are normally used. Some models allowed to adapt such data to another target station for example considering the heat island effect (Christoffer, et.al., 2011) or using monthly adjusting factors for various locations like valley, near lake (Remund, et.al., 2015). These models adjust, however, only temperature. To use for hygrothermal simulations, other climate elements like humidity, global-, atmospheric counter radiation and driving rain concerned with precipitation, wind speed and wind direction should be also adapted to a target station considering its location.

This work is a part of a research project, publicly funded by the research cluster energy efficient buildings (ENOB), to improve boundary conditions for hygrothermal simulations of building components. Within this project also new reference climate datasets, focused on the relevant climate elements for the hygrothermal performance of building components, named HRY (Hygrothermal Reference Year) have been developed (Schöner, et.al., 2016). The HRY are available for eleven zones in Germany. In order to take into account local climate effects still varying inside these zones using HRY or other reference data, the local climate model was developed.

USED CLIMATE DATA

The climate data used in this study are measured data of different locations, provided by an independent meteorological service, over a time period of five years from 1.1.2006 to 31.12.2010. These date sets contain air temperature, temperature at 5 cm above ground, relative humidity, global radiation, wind speed, wind direction and precipitation amount. The data lacks are filled and absolute humidity, diffuse radiation and atmospheric counter radiation are complemented based on the available climate elements using physical models.

PRE-STUDY OF CLIMATE DIFFERENCES BETWEEN SINGLE LOCATION PAIRS

Qualitative correlation between climate and locations within the same local region

To evaluate the climate differences according to the local conditions, different climate stations under varying local conditions (like in a city, on a mountain or near a lake) within a radius of 15 km are chosen. Table 1 shows the descriptions of the stations chosen for this evaluation.

Table 1: Four groups of climate stations with description of local condition,

GROUP	STATION	LOCATION	ALTITUDE
Hamburg	Airport	outskirts	11 m
	Veddel	industrial area with many waters	7 m
Karlsruhe	Karlsruhe	outskirts	116 m
	Wörth am Rhein	by a river	100 m
	Neuenbürg	on a mountain	214 m
Baden-Baden	Baden-Baden	city on a mountain	240 m
	Bühl	outskirts	130 m
	Bühlerhöhe	on a mountain	770 m
Lindau	Lindau	by a lake	400 m
	Argenbühl	on a mountain	684 m
	Lindenberg	on a mountain	818 m

In order to compare the climate conditions easily, each climate element is plotted as box plot shown as example for the group of Lindau in Figure 1.

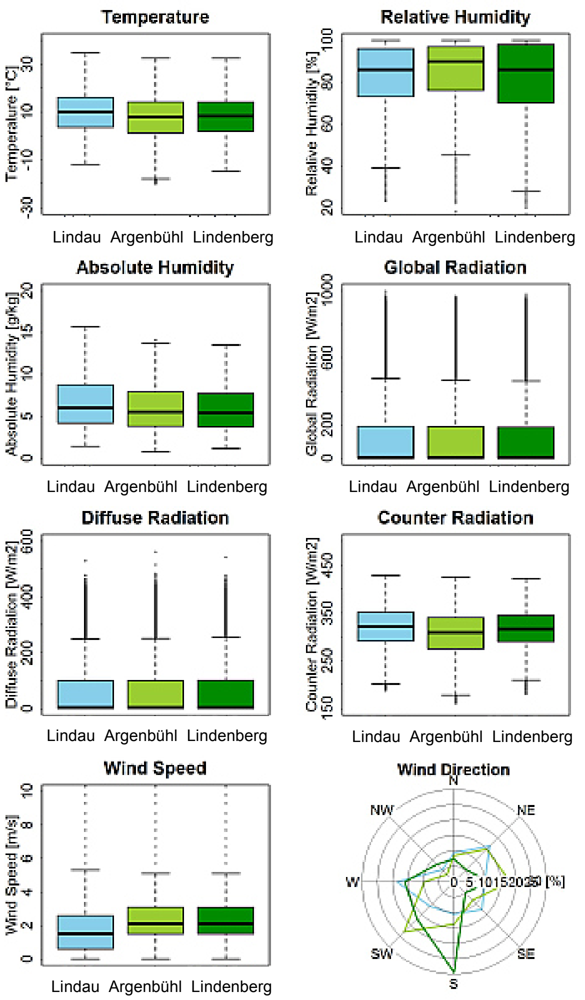

Figure 1: Box Plots of the climate elements at three stations in the group of Lindau

From the evaluation of the box plots, the following correlations can be observed:

- Temperatures generally decrease with increasing altitude of the stations.
- Absolute humidity also decreases with increasing altitude of the stations except in case of nearness to water.
- Concerning wind speed and wind direction no clear correlations with local conditions can be observed.
- The box plots of global radiation are similar at all observed stations. However, the diffuse radiation at Veddel, a region in Hamburg with many waters and channels, is higher than at the station near by the airport in the outskirts far from waters.

The observation of the climate at various locations within the same local region shows the qualitative climatic differences. As a next step, it should be tried to describe the correlation of climate and locations in a quantative way.

Correlation analysis between climate elements and area type rates

The second approach is a statistical evaluation by correlation factors for each climate element depending on local conditions. To perform the correlation analysis, the two variables should be defined quantitatively.

Therefore the mean values of each climate element over the whole measurement period are used for the stations from Table 1. To describe the local conditions, the area type around each station is analyzed by means of a map with information about topographic characteristics or usage like waters, forest, field, residential or industrial area and so on. An open source map service including such local classifications was applied for this work. A square of 4 by 4 km around each climate station is analyzed and split into the mentioned categories. Figure 2 shows the area distribution for the surrounding of each station. In addition, the altitude of the location needed to be used as influencing factor according to the observations of the previous section.

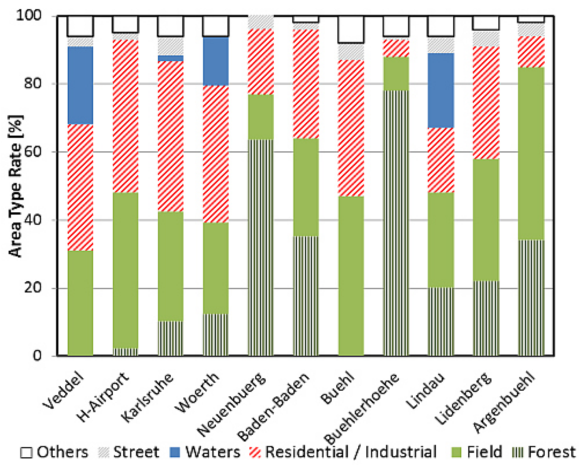

Figure 2: Area rate of each climate station

The aim is, to focus on the differences of area type rates and differences of local climate conditions between two stations of the same group. Therefore the values of the station pairs are subtracted from each other. There are eleven evaluated pairs in four different groups.

Table 2 shows the resulting correlation coefficients (*r*) between the differences of the climate element and the differences of the area type rates around the climate stations. Correlation coefficients indicate the strength and the direction of the relation between two variables by values from -1 to 1. Absolute values (|*r*|) close to 1 indicate a strong relation, while 0 means no correlation at all. The direction of the correlation is given with positive or negative numbers.

Table 2: Correlation coefficients(r) between the difference of each climate element and the difference of the area type rate for eleven station pairs

Area Type Rate resp. Altitude		CORRELATION COEFFICIENTS						
		Mean value over measurement period						
		TA	HREL	X	ISGH	DIS	ILAH	WS
Altitude		-0.91	0.19	-0.77	-0.71	0.44	-0.61	0.78
Area Type Rate	Forest	-0.70	0.56	-0.29	-0.82	0.19	-0.31	0.26
	Field	0.29	-0.50	-0.07	0.67	0.16	0.12	-0.25
	Residential/ Industrial	0.72	-0.43	0.40	0.75	-0.18	0.41	-0.38
	Waters	-0.06	0.42	0.26	-0.46	-0.29	-0.03	0.24

TA: air temperature, HREL: relative humidity, X: absolute humidity, ISGH: global radiation, ISD: diffuse radiation, ILAH: atmospheric counter radiation, WS: wind speed

The correlations between the altitude differences and temperature resp. absolute humidity differences show coefficients (r) of -0.91 resp. -0.77. The altitude has also a certain correlation ($|r|>0.6$) with wind speed, global and counter radiation. In addition the global radiation shows correlations ($|r|>0.6$) with the area type rates of „forest“, „field“ as well as „residential/industrial“, which indicates that a local adjusting of global radiation is required. The assumed correlation between the part of residential/industrial area and temperature, well known as „heat island effect“, can be confirmed while the correlation coefficient between “waters” and absolute humidity is rather low (r=0.26). The results from this static analysis indicate only some meaningful correlations between the area type rates and the different climate elements. The reasons for that could be the following ones: The number of observed stations is not sufficient, the differences of regional climates in several parts within Germany are not considered and the interaction between altitude and area type rates could also weaken the correlation. For example a location on a mountain with a high altitude will normally show a big rate of „forest“ or „field“ and a low rate of „residential/industrial“ area.

Results of the pre-study

The results of this analysis provide the following hints for the further process: Altitude and local conditions should be treated separately for the local climate models. The area type rate like defined in available maps is not suitable to describe the local conditions. The local climate should be compared with stations within the same climate region.

DEVELOPMENT OF LOCAL CLIMATE MODELS

Proceeding and adjusting method for the different climate elements

According to the results of the pre-study, it was decided to determine altitude conversion factors first. Afterwards the local climate models within limited regions are developed, using five qualitative local categories instead of quantitative descriptions. Most of the climate stations are located outskirts on a flat country. This category is called “Neutral” and serves as reference category. Further categories are “Mountain”, “Waters”, “City” and “Valley”. Their local climates are determined in difference to the category “Neutral”.

To develop the local adjusting factors, the 74 climatic data sets of stations all over Germany, divided in the eleven HRY zones, are investigated. The principle correlations between the different local categories and their climate conditions are determined, starting with the rather large and topographically inhomogeneous region, the HRY Zone 9. Finally the local adjusting factors are verified for all HRY zones and modified, if needed.

For the climate elements temperature, absolute humidity, global-, diffuse- and counter radiation at the target category, adjusting factors - described in detail later in the paper - are added to the hourly data of the reference station with the category “Neutral”.

Wind speed and wind direction are strongly affected by objects like buildings or trees (Weischet, 1995). In sheltered places wind speed tends to be lower, while in exposed places it will be higher. In order to consider these influences in addition to its local category, the ranges of wind speeds for each category are researched. Therefore the variation of the average wind speeds of 74 stations considering those categories are analyzed as well as the German wind speed map by the German Meteorological Service (DWD) is also considered, which shows the average wind speeds based on measured data from 1981 to 2000.

According to the correlation analysis, the precipitation amount shows only a weak dependency on the altitude of the stations and also only a weak correlation with the local categories. On the other hand big differences within the same HRY zones can be observed, depending on macroclimatic and topographic influences, rather independently on the local categories and partly also on the altitude. To consider the real loads, the precipitation map by the DWD can be applied. The map shows the mean annual precipitation amounts, measured from 1961 to 1990 all over Germany. Finally the average annual ratios concerning wind speed and precipitation amount between target station and reference station are multiplied with the hourly data of the reference station.

Table 3 shows the adjusting methods of each climate element considered in the local climate models. The hourly climate data of the “Neutral” reference station are treated individually.

Table 3: Adjusting methods of each climate element in the local climate models

CILMATE ELEMENT	LOCAL ADJUSTING METHOD
Temperature	Addition of a monthly local adjusting and an annual altitude conversion factor
Absolute Humidity	Addition of a monthly local adjusting and an annual altitude conversion factor
Global Radiation	Addition of a monthly local adjusting factor
Diffuse Radiation	Addition of a monthly local adjusting factor
Counter Radiation	Addition of a monthly local adjusting and an annual altitude conversion factor
Wind Direction	No local adjusting factor - manual rotation of the wind direction available
Wind Speed	Multiplication with local adjusting and additional exposure factor.
Precipitation	Multiplication with local rain load factor.

Altitude conversion

As mentioned above, the effect of altitude must be considered in the local climate model due to its strong influence on some climate elements. Thus, in a first step, conversion factors for those climate elements are defined, which strongly depend on altitude differences. For this purpose, the correlation between the altitude and the mean values of each climate element over the whole measurement period is analyzed for the 74 stations. The results show, that temperature, absolute humidity and counter radiation show a meaningful correlation with coefficients of respectively -0.888, -0.799 and -0.856. The precipitation amount shows only a vague correlation with altitude, as the coefficient is 0.674. Otherwise the correlation between the other climate elements and the altitude is rather weak with values of 0.45 for global radiation, 0.42 for diffuse radiation and only 0.07 for wind speed.

By means of point plots and their linear analyses, the conversion factors for the first three elements are determined. Figure 3 shows the point plot of the temperature and the formula for the trend line. The respectively determined altitude conversion factors are -0.0041 K/m for temperature, -0.0012 (g/kg)/m for absolute humidity and -0.021 (W/m²)/m for counter radiation. For the other climate elements no altitude conversion is determined.

Development of the local adjusting factors

To focus on the local climate differences within a limited region excluding the macro climatic influence, the 28 climate stations in the HRY Zone 9 are at first investigated. The reference station of the HRY Zone 9 is Fürstenzell with category "Neutral". "Neutral" is defined as located on the flat country, far from mountains, waters and bigger cities. Thus Fürstenzell is advantaged to specify simply the climate differences from other local categories.

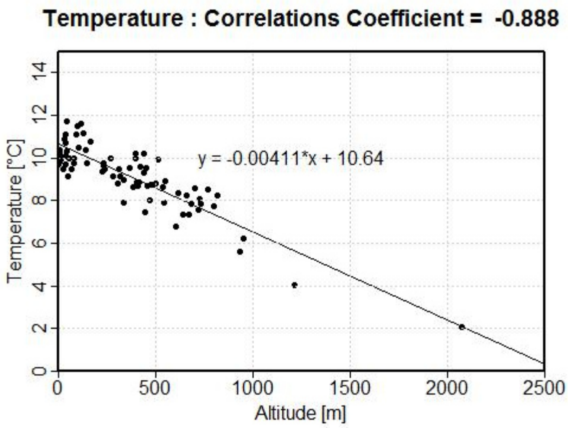

Figure 3: Point plot of altitude (x-axis) and the mean values of temperature (y-axis) for the 74 stations with resulting trend line and its formula

The following steps have been performed to develop the local climate adjusting models based on the stations in the HRY Zone 9.

<u>Identification of representative stations for each local category</u>

Each station is assigned to one of the five local categories "Neutral", "Mountain", "Waters", "City" or "Valley" based on the qualitative observation of its surroundings using also satellite pictures. One representative station is identified for each category, which meets the following requirements:

- The climate behavior at the station meets the climate features for the resp. category, generally expected or mentioned in literature like (Weischet, 1995), like high temperature in a city or low global radiation in valley.
- The climate conditions at the station represent the category on the safe side concerning the influence on the hygrothermal performance of building components. That means for example a lower temperature, a higher humidity or a lower counter radiation. The first two factors can reduce the drying potential and the last one causes a stronger overcooling during night, by more longwave emissions.

The identification of each local representative station is performed at first by comparing the climate characteristics of the stations. For that an average year is created based on the five years measurement period for all climate elements. The results are plotted in graphs like shown in Figure 4. The mean values are plotted on the X axis and the annual amplitudes as differences between the maximal and minimal monthly mean values on the Y axis. Temperature, absolute humidity and counter radiation are corrected with the conversion factors for the altitude of Fürstenzell (476 m).

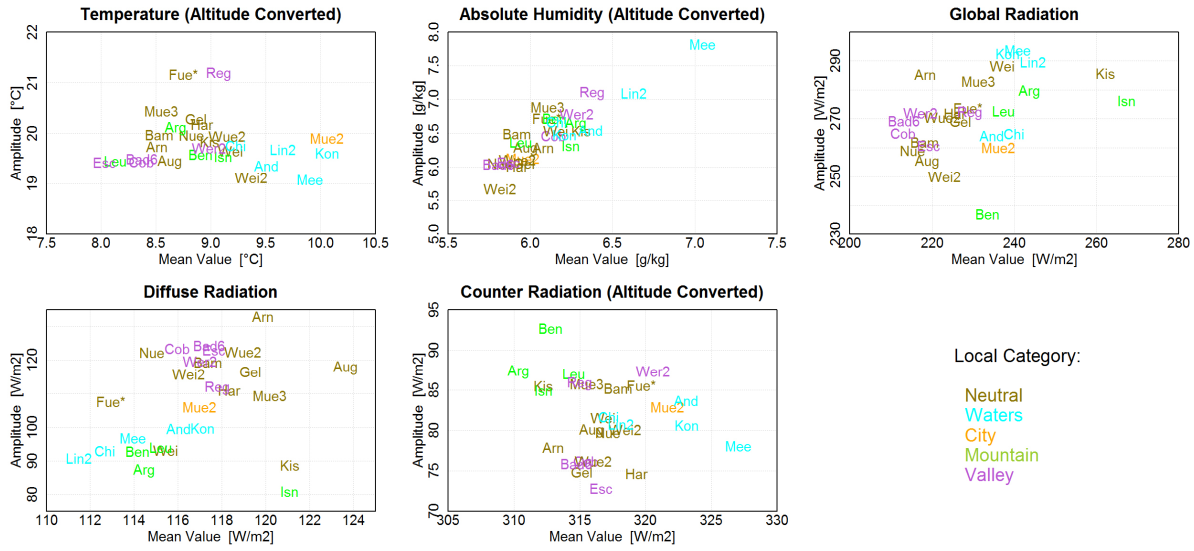

Figure 4: Point plots with the mean values (X axis) and the annual amplitude based on monthly mean values (Y axis) for 28 climate stations in the HRY Zone 9. Each point is named with the first three characters of the station and colored according to its local category.

Based on this evaluation considering the applicability also in other HRY zones, the following representative stations are finally chosen: Munich for "City", Lindau for "Waters", Eschenfelden for "Valley" and Leutkirch for "Mountain".

<u>Determination of the "local adjusting function"</u>

For each of these local representative stations the differences of its monthly mean values from those of Fürstenzell are calculated. As the curves of those monthly differences can be jaggy because of some outliers, they need to be smoothed. These curves, determined on basis of the monthly differences, to adjust the local climate, are called "local adjusting functions".

<u>Hygrothermal simulation of sensitive constructions</u>

The hygrothermal behavior of a building component simulated with the generated local climate data should be similar or more critical than that with the measured climate data. To ensure that, at first the local climate data for each local category are generated applying the local adjusting functions and the altitude conversion factors on the climate data of Fürstenzell. Then the results of hygrothermal simulations of four sensitive constructions using both of the climate data are compared.

The simulations are performed by means of the hygrothermal component simulation model WUFI® (Künzel, 1995a), developed by the Fraunhofer Institute for Building Physics. The following four constructions are simulated, as they are known from experience to react rather sensitive to the different outer climate parameters.

- Metal roof (north oriented with an inclination of 50°)
- Green flat roof
- Flat roof with white roofing membrane
- Masonry wall (west oriented with interior insulation)

For evaluation the total water content in the whole construction as well as the water content of the critical layer of each construction are considered. The critical layers are the softwood sheathing for the metal roof, the OSB in the green- and flat roof and the masonry in the wall. In the case, that the simulated water contents in the total construction or in the critical layer are lower with the generated climate than with the measured climate file, the local adjusting function needs to be further modified. When the results are equal or slightly higher compared to the measured climate file, the adjusting functions are accepted.

Figure 5 shows as an example the simulated water contents in the flat roof with the measured climate data at Eschenfelden, category "Valley" (blue line), and the generated climate file based on Fürstenzell (red line).

<u>Applicability of the models for the other HRY climate zones in Germany</u>

The determined local adjusting functions should be tested for the use in the other HRY climate zones in Germany. Therefore several stations in each zone are selected and their local categories are defined like for Zone 9.

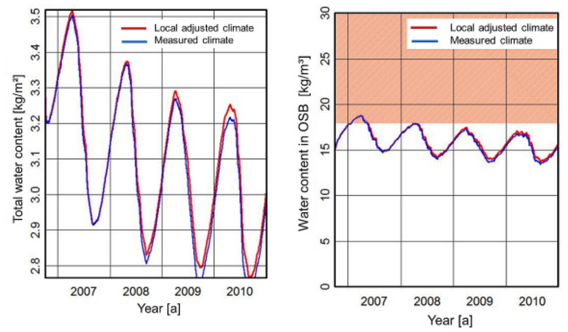

Figure 5: Total water content(left) and OSB water content (right) in a flat roof, simulated with the measured climate data at Eschenfelden (blue line) and the generated climate file with the adjusting functions of "Valley" based on Fürstenzell (red line).

For each zone the same point plots like Figure 4 (for the Zone 9) are created. The local adjusting factors for the four local categories are applied to the reference station of each HRY zone and the resulting points are added to the point plots of the different climate elements. The added points are compared with those of the measured stations of the same category in the respective zone. In case that the local adjusted points don't match to the stations in the same category but other zones, either the adjusting factor is modified or another representative station for the category in the Zone 9 is chosen for the better applicability in all zones. For example, the first chosen representative station for "Waters" Meersburg should be changed with Lindau, as the adjusting factors of absolute humidity as well as counter radiation defined based on the measured data of Meersburg are too much for the stations categorized in "Waters" in the zones of 1 and 2. Furthermore the temperature adjusting function for the category "City", based on the measured data in Munich, should be about 0.8 K lower to avoid the overestimating of the temperature applying to Berlin or Hamburg. After each change of a curve, the prior steps are repeated to ensure that the changed curves still match to the previous zones.

Figure 6 shows the procedure of the development of the local climate models.

As some of the reference climate stations in the other Zones are belonging to other categories, they need to be transferred to the category "Neutral" by applying the inverse adjusting factors first. It is also possible to combine the local adjusting functions, if the real situation fits more than one category. In addition, the local adjusting functions can be weighted from 0 to 1. For example, to create the local climate data for Veddel in Hamburg, located in an industrial area with waters and channels in-between, the factor of 0.5 for both local categories of "Waters" and "City" lead to good results. However, as a clear decision, which category and which weighting is appropriate, is often difficult, some variations are recommended, especially, when a building component shows a sensitive reaction on the changings.

Figure 7 shows the final local adjusting functions for each climate element after adaption to the different zones.

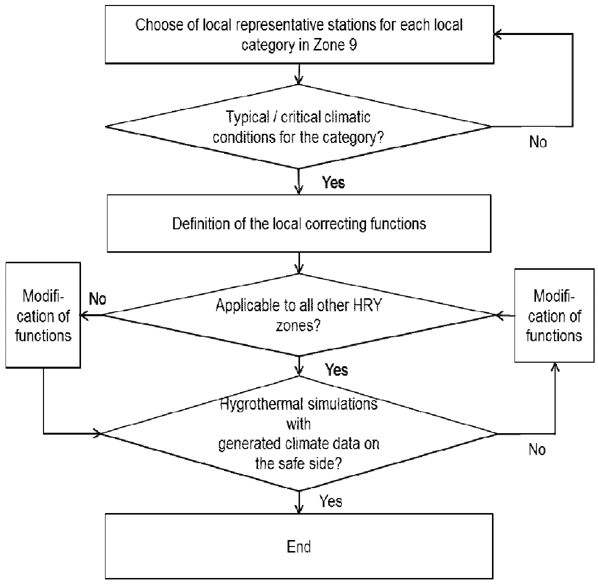

Figure 6: Procedure of the development of the local climate models

Statistical verification of the improvement

To verify the improvement of using the local climate models, the differences of the mean values between measured climate data at 74 stations and the HRY data of the corresponding zone with and without the local adjusting are compared. The box plots of each climate element are calculated and shown in Figure 8 for both, the normal reference years and the adjusted files for the local categories. The red lines at 0 K indicate the level of no difference to the measured data. The closer the box plot values come to this line, the smaller the differences to the real conditions are. Comparing the ranges shows a clear improvement of the adjusted climates concerning the spread of the data for temperature, absolute humidity, global and counter radiation. For temperature, absolute humidity and diffuse radiation also the medians and quartiles lie closer to the measured data, while they remain a bit more on the safe side for global and counter radiation. That means that the differences between the measured and the HRY data are reduced by using the local climate models. Especially overestimations concerning high temperatures and radiation loads are better prevented by the adjusted data.

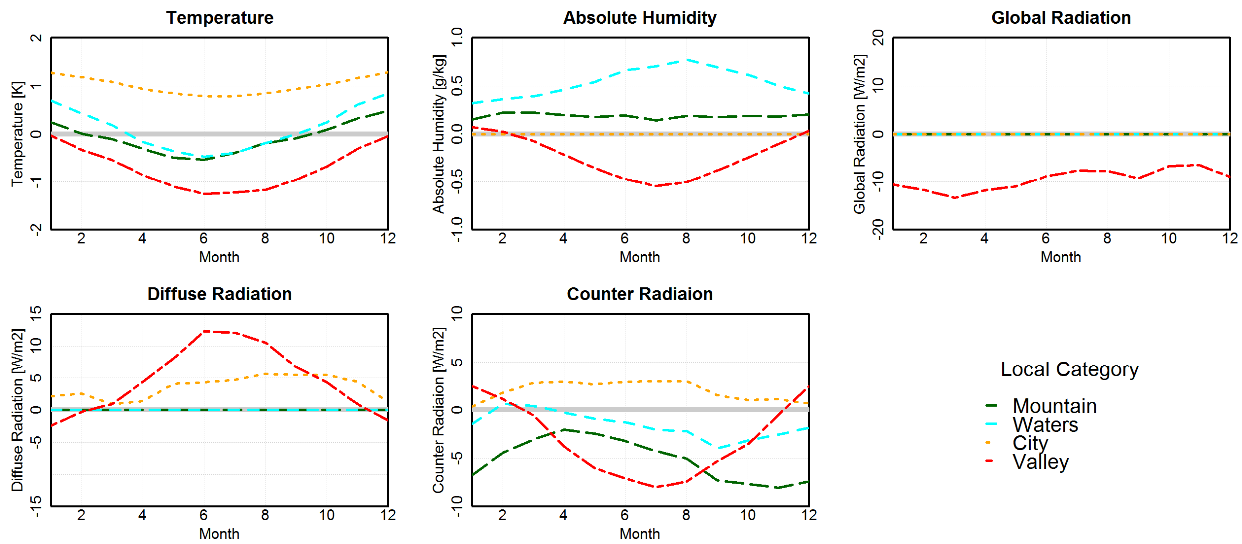

Figure 7: Local correcting functions applied for the local climate models.

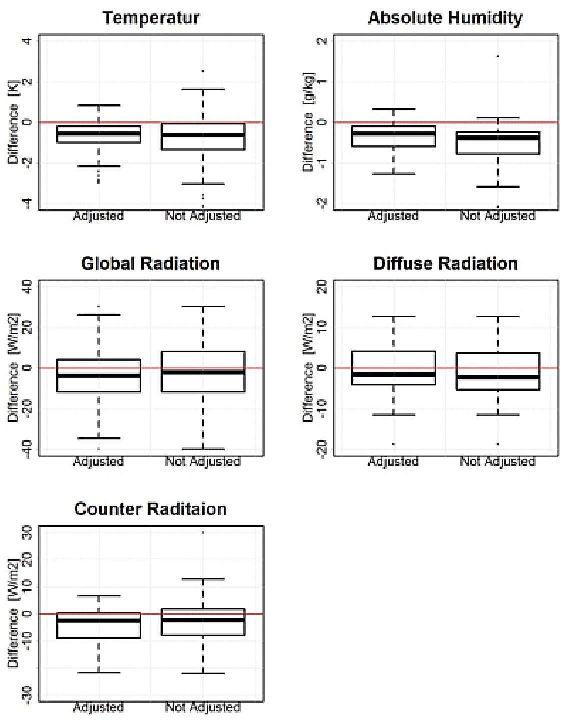

Figure 8: Differences of the measured data at 74 stations compared with the reference climate data "adjusted" using the local climate models or "not adjusted"

DISCUSSION

The pre study showed, that the data basis for detailed quantitative adaptions for local climate conditions is not sufficient.

As an alternative, qualitative local exposures were defined and typical tendencies, leading to more critical hygrothermal conditions in building components, were determined. These adjusting factors for different local categories can be applied with different weights from 0 to 1. The local adjusting functions have been developed based on measured data, fulfilling the following criteria: 1. The local climate effects, considered by adjusting functions, should be representative and applicable in the different climate zones in Germany. 2. The adjusted climate data should lead to hygrothermal simulation results on the safe side. These criteria have been verified during the iterative development process.

Regarding the climate conditions on mountains a strong dependency on specific exposure and orientation can be observed. On south orientations higher global radiation loads and temperatures can occur, leading to temporarily even more favorable conditions than at "neutral" stations. On the windward side of mountains absolute humidity, driving rain load and counter radiation can be by far higher than on the leeward side. Such variations are currently not covered by the local climate model, but could be a topic of further refinement like shading effects etc. In the current status the model represents more the critical deviation from the neutral situation like colder temperatures, higher absolute humidity and driving rain loads etc. prevailing at not sheltered positions.

Concerning the adaption of the precipitation amount the values of rain at a reference station are multiplied by a factor to increase or decrease the rain load. However the duration of the precipitation is not adjusted. As not only the amount but also the duration of precipitations have an influence on the water contents in the assembly (Künzel, 1995b), also here some further refinement considering the interaction between the precipitation and other climate elements could be of relevance.

Altogether the local influence in the new models is considered with its typical but slightly critical tendencies. Nonetheless, the climate conditions at some specific places, of course, can be actually both, more favorable or more critical than the adjusted climate data. However, creating worst case scenarios based on the most critical data, would definitely have been a simple solution, but far from reality and hardly beneficial for most practice requirements.

SUMMARY AND CONCLUSION

The new local climate models, presented in this paper, extend the possibilities to adjust the climate data of a reference station in order to transfer it to another location.

The available local climate categories, apart from 'Neutral' as standard situation, are 'Mountain', 'Waters', 'City' and 'Valley'. The development was performed with focus on hygrothermal simulation of building components. For these categories monthly adjusting functions for temperature, absolute humidity, global, diffuse and counter radiation were specified. The adaption should represent typical but rather critical conditions, allowing the identification of eventually required improvements of sensitive constructions. Also a weighted adaption and combinations of more than one local categories are possible.

In parallel to the local categories also conversion factors for altitude corrections were necessary for temperature, absolute humidity and atmospheric counter radiation.

Thus local climate models can contribute to a more realistic and safe design of building components by means of hygrothermal simulations, especially concerning all damage processes which strongly depend on local climate variations like driving rain load, high relative humidity or low temperatures.

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LOCAL CLIMATE TOOL

For practical use, the new local climate models are summarized in a user friendly software tool. Figure 9 shows a screenshot of this tool. In this tool the users can enter the required inputs easily for example choosing a reference station from the list of HRY zones and defining the local categories considering those weighting factors (0 to 1) with slide bars. Also the predefined range of annual mean wind speeds considering exposures in different local categories and the precipitation map of Germany by DWD can help users to define the input values for a target location.

As the graphs showing monthly climate mean values of a reference as well as the adjusted climate data reflect any changes of inputs, the users can see immediately the local influences on climate data. It is also available to change the wind direction seeing the driving rain rose like shown in Figure 9, which indicates the main driving rain direction.

Furthermore, not only the HRY data but also other climate files can be used as a reference data to be adjusted to another location.

The generated climate data can be exported as a climate file for hygrothermal simulations with WUFI®.

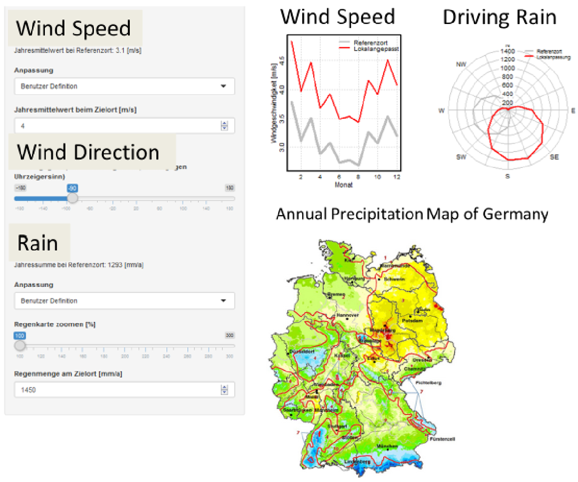

Figure 9: A screenshot of the developed local climate tool. This is the tab to adjust the wind speed, wind direction and precipitation.

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