Development of a statistical model to assess the climate conditions in the ventilation layer of double pitched roofs

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Abstract. For the proper simulation of hygrothermal processes in roof constructions with ventilation layers the knowledge of climate conditions within the ventilation layer is requisite. In this work a model for the assessment of temperature and air humidity has been developed using multiple regression analysis. Therefore, the climate conditions inside the ventilation layers of differently covered and oriented roofs have been monitored for one year. Relevant outside climate parameters for the calculation of ventilation layer climates have been identified. The comparison between measured and calculated values indicated an adequate accuracy of the developed model with limitations for the use in snow fall periods.

1 Introduction

In recent years the hygrothermal simulation became a standard process to evaluate different roof constructions for its moisture protection performance. The basis for these simulations is a defined indoor climate as well as a site-specific outdoor climate to calculate the heat and moisture transfer through the construction between the outside and inside. EN-15026:2007 [1] defines applicable indoor climate approaches for different building utilization categories. The applied outdoor climate must be representative for the building site and contain measurement data of ten years minimum or a critical reference year as alternative option [1]. For non-ventilated roof constructions, a proper simulation is already well established as the outdoor climate with its hourly parameters for temperature, air humidity and global radiation is directly available at different sources for numerous sites (e.g. Meteonorm Software [2], WUFI software climate databank [3]). In case of ventilated roof constructions, the direct application of available outdoor climate parameters is not correct. The air layer beneath the roof covering is connected to the outside air, but the microclimate (temperature, relative humidity) inside this layer is differing strongly from the outdoor climate. Heat transfer processes through the roof covering to the inside of the ventilation layer have a strong influence on temperature within the ventilation layer and thus on referring air humidity in this area. These processes strongly depend on solar absorption and long wave emission behaviour as well as on the heat capacity of the roof covering. Another important factor is the roof slope and orientation which have a big influence on the roof's absorption behaviour as a result of different shading durations. Also, the forced convection through wind as

well as the thermal buoyancy is affected in case of changing orientation and slope of the roof.

A reasonable approach to facilitate an adequate simulation of hygrothermal processes for such roof constructions is the assessment of the indoor climate of the ventilation layer on basis of outdoor climate parameters. Liersch [4] described a complex model for the calculation of physical processes within ventilated roofs. As the required input data for the detailed calculation of climate conditions according to [4] is extensive and rather difficult to determine, also other approaches have been investigated in the past. Kölsch [5] developed a simple to use method using the outdoor climate directly in WUFI simulation tool. Therefore, he adapted the heat transfer-parameters to calculate the surface temperature of the roof underlay directly to neglect the ventilation layer and roof covering in the discretized construction.

We monitored the temperature and relative humidity inside ventilation layers covered with different roof coverings on a research building with double pitched roof over 1 year. At the same time outside climate parameters have been monitored. To develop a simple to use assessment model multiple linear regression analysis was carried out in order to identify the most relevant outdoor climate parameters influencing the climate inside the ventilation layer. As a result, the identified parameters can be used to calculate an adequate and realistic temperature and air humidity development in the ventilation layers throughout the year. Finally, the calculated climate can be set as outdoor climate for the hygrothermal simulation. Similar to [5] the roof covering itself is neglected in the discretized construction.

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2 Materials and methods

2.1. Site characterization

The research building (Fig. 1) is positioned in Stetten (48°21'57.6"N 16°21'33.0"E, 169m above sea level) which is situated in western Austria. The mean annual temperature is around 10,8 °C and the mean annual air humidity is around 70 % to 75 %. Winds from NW and SE prevail. Due to the flat terrain wind velocities up to 16 m/s occur. The mean annual global radiation is around 136,5 W/m² with an average daily maximum of 350 W/m² in June and a minimum of 63 W/m² in December [2]. The roof of the building is oriented to the south and north respectively. A slight shadowing of the south oriented roof part occurs in the morning hours due to a close building in east direction. In all other directions the building is exposed freely.

Fig. 1 : The research building with different roof coverings

2.2 Roof properties

The building's double pitched roof with a slope of 33° has different roof coverings that are symmetrically arranged northerly and southerly with the same covering on opposite sides respectively. The coverings differ in material, color and ridgetype. A detailed list of the different covering types is shown in table 1. The height of the ventilation layers is 5 cm at a length of 5,52 m and identical for all material tracks. The distance between counterbattens is 60,7 cm. Protective grids were positioned on the eaves reducing the effective opening area by 50%.

2.3 Sensors and data logging

To identify which environmental climate parameters have an adequate influence on the climate within the ventilation area, the 10-minute mean values for temperature, air humidity, global radiation, UV radiation, wind direction, wind velocity and ambient air pressure were logged for over 1 year (Ahlborn FMA510 multi measurement instrument).

Table 1 : roof materials and executions.

No.	Material	color	eaves cross-section [cm ² /m]	execution	cross-section [cm ² /m]
2	brick	red	225	N-S ridge separation, ridgeroll	170
3	brick	red	225	ridgeroll	170
4	brick	red	225	ridgeroll + ventilation brick	170 + 12
5	brick	black	225	ridgeroll	170
8	brick	red	225	ridgeroll + metal ventiation band	170+210
9	concrete	red	225	ridgeroll	170
10	fibre cement	grey	225	ridge ventiation band	ca. 200
11	fibre cement	black	225	ridge ventiation band	ca. 200
14	metal	uncoated	225	Jet-Ventilation	ca. 250
15	metal	black	225	Jet-Ventilation	ca. 250
16	metal	red-brown	225	Jet-Ventilation	ca. 250
17	metal	uncoated	225	Jet-Ventilation + Ventilation brick	ca. 250

The different sensors were placed fully exposed onto a flat roof next to the research building. At the same time the 10-minute mean values of temperature and air humidity inside the ventilation areas of the different roof coverings were logged using 24 combined sensors (Ahlborn FHAD 46-2 – temperature and relative humidity sensor; accuracy relative humidity: ±2.0 % RH in range 10 to 90 % RH ±4.0 % RH in range 5 to 98 % RH; accuracy temperature: typical ±0.2 K at 5 to 60 °C maximum ±0.4 K at 5 to 60 °C maximum ±0.7 K at -20 to +80 °C) in combination with Ahlborn data logger A5690-1. One sensor per covering and orientation (N,S) was positioned in a distance of 3,68 m from eaves openings. To avoid measuring errors through thermal radiation from enclosed materials all sensors were covered by an aluminium protection pipe which was aligned parallel to the ventilation areas airflow direction (Fig. 2).

Fig. 2 : Assembled Ahlborn FHAD 46-2 combined sensor with aluminium radiation protection pipe

2.4 Data treatment and statistics

In order to investigate a connection between environment climate data and climate data in the ventilation layer it was necessary to have both measurement values at the same exact times. As there were several periods of time with slightly different time stamps for both climates the corresponding data was adjusted by linear interpolation method to ensure comparability.

Most of the common hygrothermic simulation tools use hourly mean values of relevant climate parameters as input. Therefore, it was necessary to calculate the hourly mean values of the interpolated measurement data for environmental climate and ventilation layer climate respectively.

To ensure the model can be projected for different roof slopes and orientations, the measured values for global radiation (G_e), wind direction (ω_e) and wind velocity (v_e) were qualified using the slope (α_{vl}) and orientation (β_{vl}) of the observed roofs and the solar altitude (ϵ_s) and azimuth (γ_s) of the sun (Fig. 3) as shown in equations (1) and (2). The hourly solar altitude and azimuth were interpolated with the software Meteonorm 7 [2] for the site 48,366028 °N, 16,359346 °E.

Fig. 3 : Relevant angle relations in order to determine the effective global radiation orthogonal to the roof surface ($G_{e,eff}$). ϵ_s = solar altitude. α_{vl} = roof slope. γ_s = azimuth. β_{vl} = roof orientation. Figure edited from [6].

$$G_{e,eff} = G_e / \sin(\epsilon_s) * [-\cos(90 - \epsilon_s) * \cos(\gamma_s) * \sin(\alpha_{vl}) * \cos(\beta_{vl}) + \sin(90 - \epsilon_s) * \sin(\gamma_s) * \sin(\alpha_{vl}) * \sin(\beta_{vl}) + \cos(90 - \epsilon_s) * \cos(\alpha_{vl})] \quad (1)$$

$$v_{e,eff} = v_e * \cos(\omega_e - \beta_{vl}) \quad (2)$$

$G_{e,eff}$ → global radiation in normal direction to the roof surface
 $v_{e,eff}$ → effective wind velocity in normal direction to the eaves

The absolute air humidity in g/m^3 was calculated as shown in equations (3)-(6).

$$d = p / (R_D * T) \quad (3)$$

$$p = \varphi * p_{sat} \quad (4)$$

$$p_{sat} = 610,5 * \exp[(17,269 * t) / (237,3 + t)] \text{ for } t \geq 0 \quad (5)$$

$$p_{sat} = 610,5 * \exp[(21,875 * t) / (265,5 + t)] \text{ for } t < 0 \quad (6)$$

d → absolute air humidity [g/m^3]
 p → water vapor partial pressure [Pa]
 p_{sat} → saturation vapor pressure [Pa]
 R_d → gas constant [461,51 (J/(kg*K))]
 T → absolute temperature [K]
 t → temperature [$^\circ C$]

In order to create a model to estimate the climate conditions in ventilation layers of pitched roofs multiple linear regression analysis was carried out using the interpolated and hourly averaged data. The aim was to create a simple applicable model using easily accessible data. Therefore, the most significant influence parameters were determined using multiple linear regression method. The statistical model is structured as shown in equation (7).

$$y = A_1 * x_1 + A_2 * x_2 \dots A_n * x_n \quad (7)$$

$x_1, x_2 \dots x_n$ → environment climate parameters
 $A_1, A_2 \dots A_n$ → regression coefficients
 y → temperature/air humidity in ventilation layer

The first approach was a regression including 1 year of hourly measurement data (period: 09-21-2018 to 09-20-2019) with no differentiation between day and night values. Three models were investigated for the assessment of temperature and air humidity in ventilation layers respectively (8)-(14).

$$T_{vl} = A_1 * T_e \quad (8)$$

$$T_{vl} = A_1 * T_e + A_2 * G_{e,eff} \quad (9)$$

$$T_{vl} = A_1 * T_e + A_2 * G_{e,eff} + A_3 * v_{e,eff,+} + A_4 * v_{e,eff,-} \quad (10)$$

$$d_{vl} = A_1 * d_e \quad (11)$$

$$d_{vl} = A_1 * d_e + A_2 * G_{e,eff} \quad (12)$$

$$d_{vl} = A_1 * d_e + A_2 * G_{e,eff} + A_3 * v_{e,eff,+} + A_4 * v_{e,eff,-} \quad (13)$$

$$d_{vl} = A_1 * d_e + A_2 * \sqrt{G_{e,eff}} \quad (14)$$

T_e → environment temperature [K]
 d_e → environment absolute air humidity [g/m^3]
 T_{vl} → ventilation layer temperature [K]
 d_{vl} → ventilation layer absolute air humidity [g/m^3]
 $v_{e,eff,+}$ → effective wind velocity in normal direction to the eaves (windward/upwind) [m/s]
 $v_{e,eff,-}$ → effective wind velocity in normal direction to the eaves (leeward/downwind) [m/s]
 $A_1, A_2 \dots A_n$ → regression coefficients

For the second approach the hourly values were divided into day- and night-values. At night there is no influence of global radiation on T_{vl} and d_{vl} . Hence the global radiation was omitted and models (15)-(18) were investigated for $\epsilon_s(t) = 0$ (night) in combination with models (8)-(14) for $\epsilon_s(t) > 0$ (day).

$$T_{vl} = A_1 * T_e \quad (15)$$

$$T_{vl} = A_1 * T_e + A_2 * v_{e,eff,+} + A_3 * v_{e,eff,-} \quad (16)$$

$$d_{vl} = A_1 * d_e \quad (17)$$

$$d_{vl} = A_1 * d_e + A_2 * v_{e,eff,+} + A_3 * v_{e,eff,-} \quad (18)$$

The target was to identify the most accurate combination between day and night models.

The assessment models for temperature were developed considering the measurement values of the southerly oriented ventilation layers for the regression. Afterwards they were validated by projection of the model on the northerly oriented roof surface. This was done by a subsequent comparison of the model results to the measurement values inside the northerly oriented ventilation layers. For the air humidity assessment models this was made conversely.

3 Results and discussion

Fig. 4 : Measured temperature values in comparison to calculated values from different regression approaches: over 1 year (left) ; over 500 hourly values (right).

3.1 No differentiation between day and night

Fig. 4 shows the measured temperature values in comparison to calculated values from different regression approaches for roof covering no. 4 (brick, red, ridgeroll + ventilation brick). Depending on the regression approach the accuracy of the models varies. Considering only the outside temperature (T_e) into the model is insufficient to assess the temperature inside the ventilation layer (T_{vl}). Both overall (left) and detailed (right) development indicate that the calculated values are over- or underestimated. Considering the global radiation in normal direction to the roof surface ($G_{e,eff}$) in

addition to the outside temperature indicates an adequate description of T_{vl} . The detailed development shows that all peaks are well described. Implementing the effective wind velocity $v_{e,eff,+}$ and $v_{e,eff,-}$ as a third factor into the model has no significant influence on the accuracy of the model. Nevertheless, the results of [7] have shown that the windspeed and attacking angle of the wind have a large influence on the air speed inside the ventilation layer of pitched roofs. [8] noticed a lower condensation potential (CP_i) inside ventilation layers during times with higher wind speeds as consequence of increased air change rates. Other than for temperature, global radiation and air humidity, wind velocity and wind direction are instable parameters that show high

fluctuations within seconds. As it was necessary to interpolate and average the measured values for wind velocity and wind direction to get hourly values for the simulation model the validity of those parameters might have been afflicted. Due to these reasons the wind velocity will not be regarded in the assessment model. Fig. 6 shows the measured absolute air humidity in g/m^3 in comparison to calculated values from different regression approaches for roof covering no. 4 (brick, red, ridgeroll + ventilation brick). It can be seen that the regression approach consulting only the outside absolute air humidity d_e (11) is insufficient to describe the development of d_{vl} properly. Factoring the effective global radiation ($G_{e,eff}$) in addition (12) shows a more adequate description of the absolute air humidity development in the ventilation layer. Due to global radiation higher values for T_{vl} occur in the ventilation layer whereby higher amounts of moisture can be absorbed by the air from the surrounding construction components which influences the air humidity in this layer accordingly. The same effect was found by [8]. In addition, Fig. 6 shows the slightly changed regression approach (14) that includes $\sqrt{G_{e,eff}}$. However, this approach shows no increasing accuracy applied on the data that was used to develop the model (roof covering no.4, north) with its coefficients A_1 and A_2 .

Nevertheless, the application of both models on the measured d_{vl} on the opposite side (roof covering no.4, south) shows a high overestimation of air humidity using regression approach (12) (Fig. 5). This effect can be minimized using regression approach (14) which shows an adequate description of d_{vl} .

Fig. 5 : Measured humidity values in comparison to calculated values from two different regression approaches over 600 hourly values.

Fig. 6 : Measured air humidity values in comparison to calculated values from different regression approaches: over 1 year (left); over 500 hourly values (right).

Fig. 7 : Measured temperature values in comparison to modelled values calculated on basis of two separated regression approaches for day [$\epsilon_s(t) > 0$] and night [$\epsilon_s(t) = 0$].

3.2 Differentiation between day and night

The model using a combination of approach (9) for $\epsilon_s(t) > 0$ (day) and approach (15) for $\epsilon_s(t) = 0$ (night) indicated the highest accuracy for assessing the temperature T_{vl} (Fig. 7). The assessment models for T_{vl} were created using the temperature measurement data of the southernly oriented ventilation layers. Fig. 7 indicates an adequate assessment of the temperature development inside the ventilation layer beneath roof covering no. 4 using the above-mentioned regression models for day and night respectively. Applied on the northernly oriented ventilation layers the model also shows an adequate assessment of the temperature development. However, in both cases (north and south) temperatures are slightly underestimated in summer. Higher temperatures inside the ventilation layer induce higher drying potential of roof constructions. Therefore, the underestimation causes higher safety for moisture-specific evaluations of hygrothermal simulations based on this approach. Fig. 8 shows the model for air

humidity assessment using a combination of approach (14) for $\epsilon_s(t) > 0$ (day) and approach (17) for $\epsilon_s(t) = 0$ (night). This approach-combination showed the highest accuracy among all regressions. The assessment models for air humidity in g/m^3 were developed using the measurement data of the northernly oriented ventilation layers in combination with the measured outside climate conditions. With view on Fig. 8 the model for roof covering no. 4 provides a realistic development of the absolute air humidity during the year for both roof orientations. Similar as the temperature model (Fig. 7) underestimations of the absolute air humidity occur. Especially northernly these can be seen during the whole year. Nevertheless, the model describes a realistic development for d_{vl} . Fig. 9 shows the moving 3-day average of the northern and southern development of d_{vl} (measured vs. calculated). It indicates an adequate accuracy for the northern as well as southern ventilation layer.

Fig. 8: Measured temperature values in comparison to modelled values calculated on basis of two separated regression approaches for day [$\epsilon_s(t) > 0$] and night [$\epsilon_s(t) = 0$].

Fig. 10 shows the result of the above-mentioned models pairwise (T_{vl} , ϕ_{vl}) for northern and southern ventilation layers (roof covering no. 4) respectively in spring (04-15 to 06-15) and autumn (10-15 to 12-15). The calculated air humidity development was re-calculated to relative air humidity using equations (3)-(6). It becomes apparent that T_{vl} is adequately assessed in spring and autumn. The assessment of ϕ_{vl} is properly in spring and early autumn. From 15th of November till 15th of December the models for T_{vl} and ϕ_{vl} do not describe the measured data

adequately anymore. In this time snow closed off the ventilation layer and covered the roof whereby the air circulation was cut off and air humidity increased. The snow cover also impeded solar absorption at the southern roof, whereby calculated temperatures are overestimated here. That means that the mentioned model is only applicable on condition that the evacuation of humidity from the ventilation layer and solar absorption of the roof covering is not disturbed.

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Fig. 9 : Moving 3-day average of measured air humidity in comparison to the moving 3-day average of calculated air humidity for northern and southern ventilation layers over 1 year (missing data in August and October).

Fig. 10 : Endresult of the climate assessment. Calculated development of temperature [T_{vl} (°C)] and relative humidity [ϕ_{vl} (%)] in comparison to measured development in spring (left) and autumn (right) for northern and southern ventilation layers.

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3.3 Regression models for different roof coverings

Chapter 3.1 and 3.2 showed the development of a model for roof covering no.4 (brick, red, ridgeroll + ventilation brick). The models for all other roof coverings were developed equally. The accuracy and inaccuracies are comparable to the above-mentioned model for roof covering no. 4. As indicating the highest accuracy, all

temperature models were gained on basis of approach (9) for $\varepsilon_s(t) > 0$ (day) and approach (15) for $\varepsilon_s(t) = 0$ (night). All humidity models were developed on basis of approach (14) for $\varepsilon_s(t) > 0$ and approach (17) for $\varepsilon_s(t) = 0$. The coefficients and deviations between measured and calculated values for the different roof coverings are shown in table 2. The average deviation lies between $\pm 1,4$ K and ± 3 K for the temperature assessment models and between $\pm 0,4$ g/m³ and $\pm 0,9$ g/m³ for the humidity assessment models.

Table 2 : Regression coefficients of different roof coverings for the the assessment of temperature [K] and absolute humidity [g/m³] inside the ventilation layer. Average deviations between calculated values and measured values and standard deviation of the average deviation for all models (N= north, S=south)

No.	roof covering	Temperature [K]			Deviations $\sqrt{(T_{vi,m} - T_{vi,c})^2}$ [K]				
		Day		Night	Mean		Std.Dev. (of deviation)		
		$A_{e,T1}$	$A_{e,GT}$	$A_{e,T2}$	N	S	N	S	
2	brick - red - N-S separation, ridgeroll	1,0012	0,0135	0,9979	1,46	1,96	1,30	2,01	
3	brick - red - ridgeroll	1,0007	0,0126	0,9978	1,62	2,22	1,34	1,98	
4	brick - red - ridgeroll + ventilation brick	1,0003	0,0128	0,9971	1,48	1,86	1,44	1,94	
5	brick - black - ridgeroll	1,0010	0,0160	0,9979	1,63	2,01	1,69	2,19	
8	brick - red - ridgeroll + metal ventilation band	1,0007	0,0129	0,9980	1,41	1,87	1,31	1,99	
9	concrete - red - ridgeroll	1,0014	0,0149	0,9979	1,42	1,93	1,37	2,00	
10	fibre cement - grey - ridge ventilation band	1,0027	0,0175	0,9987	1,71	2,19	1,65	2,28	
11	fibre cement - black - ridge ventilation band	1,0117	0,0145	0,9967	2,17	2,96	1,78	2,69	
14	metal - natural - jet-ventilation	1,0052	0,0092	1,0024	1,25	1,67	1,04	1,52	
15	metal - black - jet-ventilation	1,0022	0,0234	0,9978	1,96	2,44	1,75	2,61	
16	metal - brown - jet-ventilation	1,0010	0,0212	0,9968	1,71	2,34	1,61	2,47	
17	metal - natural - jet-ventilation + ventilation brick	1,0077	0,0080	1,0058	1,53	1,61	0,96	1,39	
	Model	$T_{vi} = A_{e,T1} * T_e + A_{e,GT} * G_{e,eff}$ for $\varepsilon_s(t) > 0$ $T_{vi} = A_{e,T2} * T_e$ for $\varepsilon_s(t) = 0$			$T_{vi,m} \Rightarrow$ Measured temperature values [K] $T_{vi,c} \Rightarrow$ Calculated temperature values [K]				
No.	roof covering	Absolute air humidity [g/m ³]			Deviations $\sqrt{(d_{vi,m} - d_{vi,c})^2}$ [g/m ³]				
		Day		Night	Mean		Std.Dev. (of deviation)		
		$A_{e,d1}$	$A_{e,Gd}$	$A_{e,d2}$	N	S	N	S	
2	brick - red - N-S separation, ridgeroll	1,0182	0,0291	0,9693	0,54	0,50	0,50	0,53	
3	brick - red - ridgeroll	0,9898	0,0849	0,9460	0,60	0,51	0,56	0,47	
4	brick - red - ridgeroll + ventilation brick	0,9979	0,0882	0,9475	0,57	0,53	0,60	0,46	
5	brick - black - ridgeroll	1,0108	0,0142	0,9696	0,38	0,92	0,32	0,99	
8	brick - red - ridgeroll + metal ventilation band	1,0344	0,0268	0,9868	0,44	0,45	0,41	0,48	
9	concrete - red - ridgeroll	0,9156	0,1062	0,8582	0,83	0,76	0,78	0,62	
10	fibre cement - grey - ridge ventilation band	0,9590	0,0936	0,8931	0,61	0,58	0,59	0,61	
11	fibre cement - black - ridge ventilation band	0,8965	0,0780	0,8277	0,55	0,63	0,51	0,76	
14	metal - natural - jet-ventilation	0,9392	0,0535	0,9058	0,39	0,49	0,41	0,38	
15	metal - black - jet-ventilation	0,9154	0,0597	0,8636	0,54	0,69	0,46	0,89	
16	metal - brown - jet-ventilation	0,9299	0,0687	0,8775	0,53	0,52	0,47	0,53	
17	metal - natural - jet-ventilation + ventilation brick	0,9739	0,0385	1,0100	0,44	0,64	0,44	0,63	
	Model	$d_{vi} = A_{e,d1} * d_e + A_{e,Gd} * \sqrt{G_{e,eff}}$ for $\varepsilon_s(t) > 0$ $d_{vi} = A_{e,d2} * d_e$ for $\varepsilon_s(t) = 0$			$d_{vi,m} \Rightarrow$ Measured humidity values $\left[\frac{g}{m^3}\right]$ $d_{vi,c} \Rightarrow$ Calculated humidity values $\left[\frac{g}{m^3}\right]$				

4 Conclusion

In scope of this work an empiric statistical model for the assessment of climate values within the ventilation layer of double pitched roofs has been developed. The data for the model development covered one year of measurement data. The results showed that outside temperature, relative humidity and global radiation as input parameters are sufficient to calculate a realistic climate development inside ventilation layers. The calculated climate described the measured climate adequately almost throughout the whole year. The values for global radiation, temperature and relative humidity are easily accessible for numerous climate stations. Therefore, the practical applicability of the developed model is higher as the rather complicated model according to [4]. Different to [5], this model focuses on

the climate (temperature, rel. humidity) inside the ventilation layer. [5] calculates the surface temperature of the roof underlay directly. The climate conditions inside the ventilation layer remain unknown. Also, the developed model enables additional roof coverings to be regarded. Whereas [5] focuses on brick and concrete coverings, this work also focused on metal and fibre cement coverings in different colors. Nevertheless, it is necessary to validate the models using climate data from buildings situated on other sites with other roof orientations, ventilation layer heights and roof slopes. Basic requirement for the applicability of the model is a working removal of humidity from the ventilation layer (i.e. no snow or dirt barriers at openings). In summertime the calculated temperature and air humidity is slightly underestimated over a longer period. Accordingly, the drying of roof-constructions in summer will also be

underestimated if the model is used as basis for hygrothermal simulations. Positive results of corresponding simulations are therefore valid with additional safety. Valid heat transfer coefficients (ventilation layer $\leftrightarrow$ roof underlay) for these simulations still need to be determined. Due to the necessary data interpolation in this work the implementation of wind parameters into the model did not increase the accuracy of the calculations. Previous works ([7],[8]) found an influence of wind speed and attacking angle on the climate inside ventilation layers.

Therefore, some of the inaccuracies of the present models might be explained by the missing wind influence.

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