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Comparing Canadian and Norwegian moisture indices for building climate adaptation

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Comparing Canadian and Norwegian moisture indices for building climate adaptation

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Abstract. To evaluate the suitability of materials and solutions in building envelopes, it is necessary to quantify the relevant climate loads. The critical climate load is typically a combination of multiple parameters, such as temperature and precipitation. Climate indices may be used for finding critical climate loads, and their use helps guide design choices when adapting to local climates. The purpose of this study is to evaluate the suitability of the Canadian Moisture Index (MI) for use in Norway. The values of MI are linked to design recommendations in the Canadian building code, thus enabling a tangible link between index values and moisture design practice. MI has been calculated for 12 locations in Norway, and compared to two indices already in national use: the driving rain index (DRI) and wood decay potential index (WDPI). The applicability of a climate index as a design tool depends on (1) describing a relevant climate stress; (2) logical differentiation of values, and; (3) translating index values to design recommendations. These are fulfilled for MI in a Canadian context, thus making it applicable as a design tool. However, significant adaptation may be required for the index to be adopted to a Norwegian context. As MI and DRI have a similar field of application, introducing MI into a Norwegian context may therefore be redundant. A drawback with the Norwegian indices is the relative weak link between index values and design recommendations, thus further development of recommendations based on index values may improve their applicability as design tools.

1. Introduction

1.1. Background

Climate adaptation of buildings in Norway requires a change of both policy and practice, to embrace knowledge of climate change, local climatic conditions and traditional local building methods [1]. It is estimated that 60 to 80 % of building defects in Norway are related to moisture [2]. Precipitation is the source of moisture in around 40 % of moisture defects reported to SINTEF between 2017 and 2020, with an increasing trend of rain intrusion related damages occurring after 2010 [3]. As building defects are becoming increasingly prevalent in the face of climate change [3], climate adaptation becomes ever more important [4].

There is currently a challenge in that buildings are designed for the same climate loads independent of their location in Norway. Climatic loads can be very harsh in certain areas, making it necessary to discourage the use of certain materials or solutions in exposed locations [5].Generic descriptors such as “cold areas” or “wind-exposed areas” are not considered sufficient to guide geographically differentiated design choices [6]. Unlike for snow or wind loads, in Norway there exists no comprehensive design methodology based on quantified moisture loads in a building design process [7], and moisture design is generally limited to a safe/not safe evaluation. Climate indices have therefore been introduced as a tool for practitioners to guide design choices in adapting to the local climate.

Presently, multiple climate indices exist to enable geographically differentiated design of building envelopes. However, recommendations linking indices to specific building design solutions are lacking for most indices. Examples of indices in Norway include the frost deterioration index for porous materials [8], the wood decay potential index [9] and the driving rain index [10]. The climate indices should be used to guide assessments related to the performance of the building envelope. Additionally, they may be used to define specific performance requirements [11] and to present future climate scenarios [5]. In the Canadian building code, a moisture index is being used to define specific solutions for moisture-resilient building design [12].

As evident by the prevalence of moisture-related defects and great geographical variations within Norway, there is a need for a structured framework that facilitates climate adaptation on a local level.. Moisture indices may become an important tool in such a framework.

1.2. Inspiration from Canada
The Canadian Moisture Index (MI) is a combination of two other indices: The Wetting Index (WI) and the Drying Index (DI) [13]. WI addresses the supply of moisture in the form of rain at each location, whereas DI addresses the local climate's ability to remove moisture through absorption to the air. The definitions of WI and DI are given in Section 2.2.

MI is used to aid moisture resilient building design in the Canadian building code [12]. It is used to determine the need for a capillary break behind façade cladding materials and to evaluate the need to use pressure-treated wood for load-bearing timber frames. MI has also been demonstrated to be useful to assess impacts of climate change [14].

1.3. Objective and scope
Lack of quantitative metrics by which to evaluate the local climate may impede climate adaptation. Climate indices are expected to be a useful tool in building moisture design to quantify the design loads. However, it remains an unresolved challenge, beyond the scope of this paper, that no sufficient link has been established between the climate indices and moisture design recommendations in Norway [15, 16]. The purpose of this study is therefore to evaluate the suitability of MI for use in Norway. MI is used as a reference in the Canadian building code [12], which bases recommendations of moisture safe façade solutions on MI index values. As a possible way to bridge the gap between index values and design recommendations in Norway, MI values are calculated and compared to two Norwegian climate indices already in national use. The purpose of this study is to (1) evaluate the key differences between the Norwegian and Canadian indices, and (2) to evaluate how to better incorporate climate indices in Norwegian building moisture design based on the characteristics of the three indices.The following research questions are investigated:

1. What are the key differences between the Canadian moisture index (MI), the driving rain index (DRI) and the wood decay potential index (WDPI)?
2. How can the climate indices be applied as a tool for assessing materials and solutions in a practical context?
3. What are the barriers to be overcome for the climate indices to be adapted for moisture safe building design in Norway?

The following limitations to the research are identified: This study does not consider the relation between climate indices and the actual climate loads that affect materials and solutions. As such, it makes no attempt to evaluate which index is the "best" one to gauge actual climate loads. Only exterior moisture loads from the air (rain and air humidity) are included, not interior humidity or moisture in the ground. Climate data from Norway is obtained using climate files taken from the hygrothermal simulation program WUFI® Pro (WUFI), developed by the Fraunhofer Institute for Building Physics, which is limited to 12 Norwegian cities. The climate files are based on historical measurements from 1961-1990, which means both present and future effects of climate changes are disregarded. However, the effects of climate change are considered to have a limited influence on the conclusions, as the climate data is used for comparing differences between climate indices. The sensitivity analyses are conducted using the Trondheim climate file.

2. Method

2.1. Climate data

Calculation of the indices are based on the moisture design reference year (MDRY) weather files developed by Geving [17]. These are also integrated in WUFI. Geving constructed MDRY for 12 locations in Norway with hourly resolution, based on historical climate data from the period 1961-1990. The MDRY is selected as a single year of measurements in the period for each location, chosen as the closest to a 10-year return period of simulated moisture content in 6 different structural assemblies.

For WDPI and DRI, the calculations are compared to indices calculated by Lisø et.al. [5] and Rydock et.al. [10], based on the meteorological normal year for the same period, as defined by the Norwegian Meteorological Institute [18].

2.2. Moisture Index (MI)

MI is calculated according to equation 1 for all 12 locations using the MDRY weather data set described in Section 2.1, according to the procedures given by the Moisture Management for Exterior Wall Systems project (MEWS project) [19].

$$MI = \sqrt{WI_N^2 + (1 - DI_N)^2} \tag{1}$$

Where WI_N is the normalized Wetting Index, and DI_N the normalized Drying Index. WI is defined as the annual precipitation in [mm/year], corrected for snow, by subtracting all precipitation in co-occurrence with temperatures below 0 °C. DI describes the drying potential given in [$kg_{water}/kg_{dry\ air}$], defined by equation 2.

$$DI = \sum_{n=1}^{8760} w_{sat}(n) - w_{amb}(n) \tag{2}$$

Where $w_{sat}(n)$ is the water content of 100% saturated air at hour n, and $w_{amb}(n)$ is the actual water content in the ambient air at hour n. The calculated values for WI and DI are then separately normalized as unitless values. The normalization scheme significantly influences the resulting MI values and should be selected carefully. To assess how the results will be affected, a total of 4 different normalization schemes have been evaluated (see **Table 1**). Schemes 1-3 are normalized relative to three different values of WI, 1000 mm, 1500 mm, and WI_{max} = 2400 mm, and relative to DI_{max} = 19.6 kg/kg. WI_{max} and DI_{max} refer to the maximum values of WI and DI found in the climate set. Scheme 4 is based on the normalization formula proposed by Cornick et al. [13].

Table 1. Selected normalization schemes of DI and WI, for calculation of MI

	MI1	MI2	MI3	MI4
N_{DI}	$DI_N = \frac{DI}{DI_{max}}$	$DI_N = \frac{DI}{DI_{max}}$	$DI_N = \frac{DI}{DI_{max}}$	$DI_N = \frac{DI - DI_{min}}{DI_{max} - DI_{min}}$
N_{WI}	$WI_N = \frac{WI}{1000\ mm}$	$WI_N = \frac{WI}{1500\ mm}$	$WI_N = \frac{WI}{WI_{max}}$	$WI_N = \frac{WI - WI_{min}}{WI_{max} - WI_{min}}$

2.3. Wood Decay Potential Index (WDPI)

WDPI is calculated according to equation 3, given by Scheffer [9], for all 12 locations using the MDRY weather data set described in Section 2.1.

$$WDPI = \frac{\sum_{Jan}^{Des}(T-2)(D-3)}{16.7} \tag{3}$$

Where T is the monthly average temperature, and D is the number of days in a month with more than 0.25 mm precipitation. It is divided by 16.7 to scale the index for a range [0, 100]. Lisø et.al [5] previously calculated WDPI for a set of locations of the meteorological normal year for the period 1961-1990. Where these locations overlap, the results for the normal year calculations are presented for comparison (see **Table 2**).

2.4. *Driving Rain Index (DRI)*
DRI is calculated for all 12 locations using the MDRY weather data set described in Section 2.1, according to the procedures given by Rydock [10]. It is defined as:

$$I_\theta = 0.206 \cdot \sum_{D=0}^{360} V_D \cdot r_D \cdot \cos(D - \theta)$$

Where D is the wind direction relative to north, V_D is the median wind velocity in direction D [m/s], r_D is the median yearly precipitation co-occurring with wind in direction D [mm], and θ is the angle between north and a line normal to the surface of the façade face. The equation is multiplied by a correction factor 0.206 [s/m], based on the assumption that a 1 mm precipitation delivers 0.206 mm of wind driven rain on a vertical surface, given a wind speed of 1 m/s [10].

The standard NS-EN ISO 15927-3:2009 describes a different method for calculating driving rain, based on hourly values [21]. This method is more precise, but only 51 weather stations in Norway have recorded hourly values of wind and rain in a time series sufficiently long to be applicable. Most of these are in climate zones with low driving rain exposure. Thus, the driving rain index calculated both in this study and by Rydock is based on daily measurements.

3. Results

3.1. *Driving Rain Index (DRI) and Wood Decay Potential Index (WDPI)*
The calculated values of DRI and WDPI for the 12 locations studied are presented in **Table 2**. For the purpose of comparison, the values for DRI are provided as were previously calculated by Rydock et al. [10], and that were based on the meteorological normal year for the same period. Note that the normal year used by Rydock et.al. is based on the same measured climate data as that used for the moisture design reference year.

Table 2. Driving Rain Index, DRI, and Wood Decay Potential Index, WDPI, for the 12 studied locations, based on the moisture design reference year (suffix = MDRY) 1961-1990 and the meteorological normal year (suffix = N) 1961-1990. Values for DRI-N and WDPI-N are collected from Rydock et al. [10] and Lisø et al [5].

Location	DRI-N	DRI-MDRY	WDPI-N	WDPI-MDRY	Ratio DRI (MDRY/N)	Ratio MDRY (MDRY/N)
Kristiansand	401	589	50	64	1.47	1.28
Oslo	196	168	48	37	0.86	0.78
Gardermoen	213	207	-	37	0.97	-
Kise	-	68	-	35	-	-
Bergen	1423	1496	70	64	1,05	0.91
Kristiansund	-	1035	-	74	-	-
Røros	111	58	28	35	0.52	1.26
Trondheim	368	613	-	49	1.67	-
Værnes	513	310	52	25	0.60	0.47
Mo i Rana	-	753	-	41	-	-
Tromsø	474	448	33	26	0.95	0.80
Karasjok	49	11	26	13	0.33	0.44

3.2. *Moisture Index (MI)*
Figure 1 shows the values for DI and WI calculated for the 12 locations in the data set with no normalization, as described in Section 2.1. The relative differences in temperature (related to the drying index on the y-axis) and precipitation (related to the wetting index on the x-axis) in the Norwegian

climate is evident. The calculated MI values for the 12 locations studied, and with the 4 different normalization schemes, as described in Section 2.2, are shown in **Table 3**.

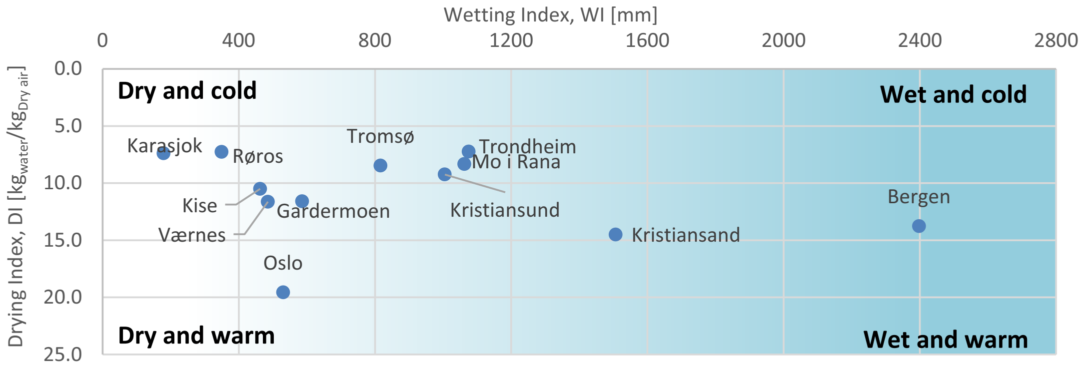


Figure 1. Calculated DI (drying capacity), and WI (annual precipitation) for 12 cities in Norway

Table 3. Moisture index calculations for 12 locations in Norway, based on 4 different normalization schemes and based on moisture design reference year MDRY-1961-1990 weather data.

Pre-normalization values			MI1 (N_{DI} = 19,6 N_{WI} = 1000)			MI2 (N_{DI} = 19,6 N_{WI} = 1500)			MI3 (N_{DI} = 19,6 N_{WI} = 2400)			MI4 $I_N = (I-I_{min})/(I_{max}-I_{min})$		
Location	DI [kg/kg]	WI [mm]	DI_N	WI_N	MI1	DI_N	WI_N	MI2	DI_N	WI_N	MI3	DI_N	WI_N	MI4
Kristiansand	14.5	1507	0,74	1.51	1.53	0,74	1.00	1.04	0,74	0.63	0.68	0,74	0.60	0.73
Oslo	19.6	531	1.00	0.53	0.53	1.00	0.35	0.35	1.00	0.22	0.22	1.00	0.16	0.16
Gardermoen	11.6	586	0.59	0.59	0.71	0.59	0.39	0.56	0.59	0.24	0.48	0.59	0.18	0.67
Kise	10.5	463	0.54	0.46	0.65	0.54	0.31	0.56	0.54	0.19	0.50	0.54	0.13	0.75
Bergen	13.8	2398	0.70	2.40	2.42	0.70	1.60	1.63	0.70	1.00	1.04	0.70	1.00	1.11
Kristiansund	9.2	1005	0.47	1.01	1.14	0.47	0.67	0.85	0.47	0.42	0.67	0.47	0.37	0.92
Røros	7.3	350	0.37	0.35	0.72	0.37	0.23	0.67	0.37	0.15	0.65	0.37	0.08	1.00
Trondheim	7.2	1076	0.37	1.08	1.25	0.37	0.72	0.95	0.37	0.45	0.77	0.37	0.40	1.08
Værnes	11.6	485	0.59	0.49	0.63	0.59	0.32	0.52	0.59	0.20	0.45	0.59	0.14	0.66
Mo i Rana	8.3	1063	0.43	1.06	1.21	0.43	0.71	0.91	0.43	0.44	0.73	0.43	0.40	1.00
Tromsø	8.5	817	0.43	0.82	0.99	0.43	0.54	0.79	0.43	0.34	0.66	0.43	0.29	0.95
Karasjok	7.4	179	0.38	0.18	0.65	0.38	0.12	0.63	0.38	0.07	0.63	0.38	0.00	0.99

3.3. Index comparisons
To analyse how the different indices correlate with each other, the values for each index are shown, in **Figure 2**, relative to the value for Oslo MDRY-1961-1990 climate. DRI takes wind speed into account, and the values may therefore not be directly comparable to MI and WDPI values.

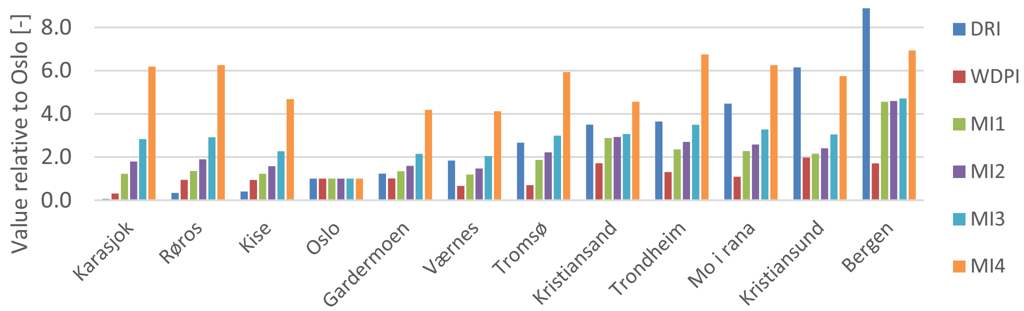
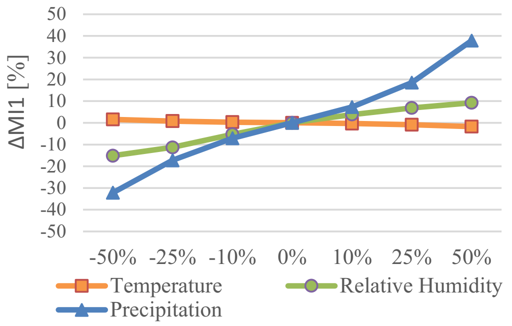
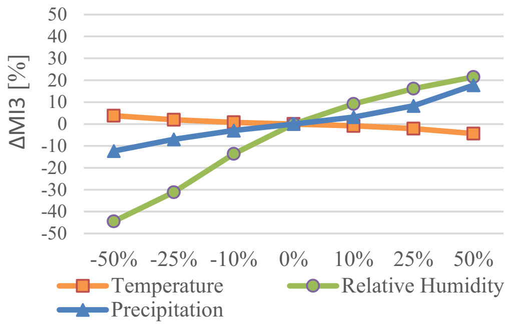


Figure 2. Driving Rain index (DRI) Wood Decay Potential index (WDPI), and Moisture indices (M1-M4) normalized for Oslo climate. Locations are sorted by increasing values of DRI from left to right.

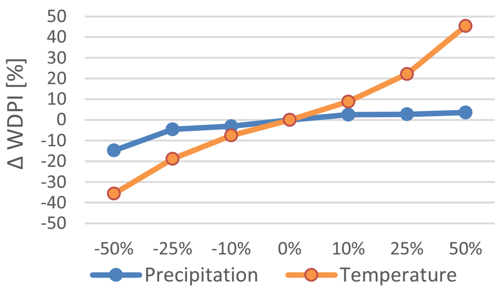
To compare how MI, DRI and WDPI are influenced by the different climate parameters, a sensitivity analysis has been performed (see **Figure 3**Results). The key parameters for each index are changed with a factor k, varying ± 10%, 25% and 50%, while all other parameters remain constant. For temperature, the changes have been set relative to the difference between the average yearly temperature for Trondheim and 0 °C, yielding hourly temperature changes ± 0.54 °C, 1.34 °C and 2.68 °C respectively for ± 10%, 25% and 50%.



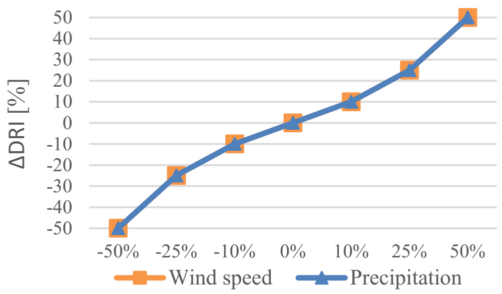
(a) Sensitivity of MI1 (N_{WI} = 1000 mm, N_{DI} = 30)



(b) Sensitivity of MI3 (N_{WI} = 2400 mm, N_{DI} = 30)



(c) Sensitivity of WDPI



(d) Sensitivity of DRI

Figure 3. Sensitivity analysis of indices MI1, MI3, WDPI and DRI

4. Discussion

4.1. Key differences between MI, DRI and WDPI

A fundamental difference between the Canadian MI and the two Norwegian climate indices, WDPI and DRI, is the complexity. MI is the most complex of the three, combining two independent indices to a single index. The behavior of MI is highly influenced by the normalization scheme, due to this complexity (see **Table 3**). Normalizing correctly is therefore vital if the index should be used in a Norwegian context. A general difference between MI and the two Norwegian indices is the index sensitivity to temperature. WDPI and DRI index values clearly increase with increasing temperature, while MI values are relatively unchanged (see **Figure 3**). If anything, warmer climates tend to yield lower MI index-values due to the increased drying potential. But this will also increase the risk of organic growth, which may not be adequately expressed by the MI index. The two coldest and driest climates in the set, Karasjok and Røros, yield higher MI index values than Oslo climate for all MI normalization schemes. Traditionally these two climates are thought of as low-risk locations with respect to organic growth. This view is also supported by the calculated DRI and WDPI index values, as both indexes show significantly lower values for Karasjok and Røros compared to the coastal areas, i.e. Kristiansund (see **Table 2**).

DRI describes the moisture load on vertical exposed surfaces in a given climate. It is only applicable to vertical surfaces, thus describing a specific climate stress for a specific field of application. In the Canadian Building code [12] MI is only used to differentiate façade solutions, and as such, the field of application is expressed through the recommendations rather than the index parameters themselves.

WDPI is a compound index describing the combined stress of temperature and moisture, indirectly expressing material degradation stress due to organic growth. The applicability of WDPI is specific, as it applies to wooden materials. However, the rain exposure of the building part being considered must be assessed before evaluation of the in-situ climate stress can be made. Currently the guidelines describing WDPI in Norway give no design recommendations based on index values. As a climate risk assessment tool, it can thus be said to be less complete than DRI and MI.

4.2. Index applicability and correlation with real world degradation
For a climate index to be applicable as a tool for assessing materials and solutions in a practical context, it needs to fulfil a set of three premises:

1. The index must describe a relevant climate stress for the considered material or building part.
2. The relative differences in actual climate stress must be correctly reflected by the relative scaling between index values throughout the index scale.
3. The climate stresses described by the absolute index values must be correlated to the response of a material or building part, to translate index values into design recommendations.

The Canadian building code differentiate wall assemblies by excluding less robust solutions when MI exceeds a certain value. MI fulfils the first premise when applied to the wall assemblies described in the code, and the normalization scheme developed by the MEWS project [19] ensures that the second is fulfilled. The building code itself supplies the third premise, by stating which solutions are applicable based on the values of MI. The Norwegian building code treats moisture safety design less explicitly than the Canadian, by defining a set of functional requirements for building solutions rather than specific solutions [20]. Thus, interest groups and research organisations such as SINTEF have developed climate indices and solution recommendations as guiding tools to meet the requirements of the building codes. Through the guidelines published by SINTEF the DRI index fulfils the three premises similarly to MI in the Canadian building code. As discussed in Section 4.1 for WDPI, premise 3 is, to date, lacking and it is therefore somewhat neglected in Norwegian moisture design practice.

4.3. Barriers for implementation of MI in Norwegian moisture safety building design
To implement MI in Norwegian moisture safety design, substantial work needs to be done in fulfilling premise 2 and 3. Norway spans from 58 to 71 degrees north, and includes coastal, mountainous, and inland regions. MI must therefore be normalized so it scales “all four varieties” of wet/dry and cold/warm regions accurately relative to each other. As seen by comparing diagrams (a) and (b) in the sensitivity analysis presented in **Figure 3**, the normalization scheme alters MI sensitivity to relative humidity and precipitation. The normalization schemes studied in this paper all seem to underestimate the moisture loads in coastal regions such as Kristiansund, compared to the two Norwegian indices (see **Table 3** and **Table 2**). In addition, the normalization schemes seem to overestimate the moisture loads in dry and cold areas, traditionally thought of as low-moisture-stress-regions, such as Karasjok and Røros. The field of application for MI specified in the Canadian building code overlaps the field of application for DRI in the Norwegian building guidelines, as discussed in Sections 4.1 and 4.2. It is outside the scope of this study to assess which of the two fulfils premise 1 most precisely. However, as DRI already fulfils premise 2 and 3 in a Norwegian context, and has a similar field of application, implementing MI to the Norwegian system seems to be both labour intensive and redundant.

5. Conclusion and future work
The key difference between MI and the Norwegian indices, DRI and WDPI, is the complexity. The behaviour of MI is sensitive to the normalization scheme, and applying MI to a new climate set with high variation in both temperature and precipitation requires careful consideration. As MI and DRI have the same field of application (facades), introducing MI into a Norwegian context may be redundant.

MI and DRI are both applicable as moisture safety design tools for their area of use, as they fulfil all three premises described in Section 4.2. Correlations between index values and design recommendations are not currently established for WDPI in Norway, reducing its usefulness as a design tool. Future work on implementing climate indices as part of building moisture design in Norway should be directed towards better integration of the existing indices in moisture design recommendations and guidelines.

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