REBUTTAL TO “ENTHALPY EVALUATION – A CASE FOR THE E^3 DRYING METRIC

A peer-reviewed alternative perspective

Abstract

A review of the claims made in the whitepaper identifies discrepancies, uncorroborated assumptions, errors, and omissions that warrant closer inspection.

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This whitepaper was written to identify some of the discrepancies, errors and omissions found in the whitepaper, Enthalpy Evaporation Evaluation — A Case for the E^3 Drying Metric authored by Chuck Dewald, III. On page 17 of his whitepaper, the author says, “I am always open to input or critique.”

Careful review of the sources and data listed in the paper in addition to an industry peer review have resulted in the identification of multiple issues that call into question some of the statements and information included in the Dewald-authored paper.

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Rebuttal to “Enthalpy Evaporation Evaluation — A Case for the E^3 Drying Metric”

1. Preface

This document serves as a structured, peer-reviewed rebuttal to the work by Chuck Dewald, III, "Enthalpy Evaporation Evaluation — A Case for the E^3 Drying Metric." References to Chuck Dewald, III, (the author) specifically highlight his perspectives and claims concerning the E^3 calculation.

The author’s paper introduces “E^3” as a proposed metric for the restoration industry, intended to evaluate drying or evaporation rates. He asserts:

> *“The restoration industry has never had a singular metric to evaluate the drying or evaporation rate. This has been a huge problem in the restoration industry since its inception. We needed a metric that could evaluate any ambient condition and provide a proportionate drying or evaporation rating. E^3 provides this metric.”*
>
> *“E^3 evaluates any ambient conditions and predicts the relative drying or evaporation rate that will be created on the wet materials by the ambient air. The system performs a thorough energy evaluation and provides a proportionate number—meaning an E^3 number of 200 would dry or evaporate water from all materials twice as fast as an E^3 number of 100.”*[1]

This claim warrants scrutiny and this peer-reviewed rebuttal evaluates the validity of the claims asserted by Dewald.

2. Executive Summary

"Enthalpy Evaporation Evaluation — A Case for the E^3 Drying Metric" (E^3) contains a number of apparent errors, omissions and unsubstantiated claims. The claim that *“E^3 evaluates any ambient conditions and predicts the relative drying or evaporation rate that will be created on the wet materials by the ambient air,”* is refuted by comparing E^3 values across a number of conditions.[2] In this regard, E^3 can be shown to be flawed across all conditions and therefore should not be utilized to provide proportional relative drying or evaporation rates.

None of the “third-party” data provided by the paper offers statistically relevant results to support the author’s claims about E^3, either through incomplete data, improper analysis on the part of the author, or by comparing unrelated fields/experiments with a metric intended for use in drying hygroscopic materials under normal atmospheric pressure. The author’s white paper contains a

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[1] Dewald, C. III. Enthalpy Evaporation Evaluation – A Case for the E^3 Drying Metric White pages. p. 2. (.pdf created 6/29/2023).

[2] Ibid. p. 3

number of values presented as being derived from the third-party data, where these presented values do not correlate with the actual cited data.[3] Some E^3 values are presented for ambiguous conditions with no clarification given as to how they were calculated.[4]

Dewald’s white paper does not appear to have undergone an industry-accepted peer review process.

Even when assuming material temperatures will trend to ambient air temperatures, the author’s claim lacks empirical support and does not align with established scientific principles related to drying rates, evaporation processes, or the known forces which influence how water molecules move through hygroscopic materials and assemblies. Without a positive correlation between E^3 and drying forces/rates, further applications such as equipment comparisons and target values cannot be considered as appropriate.

While the E^3 metric might demonstrate some level of proportionality in specific, limited drying scenarios, it fails to consistently correlate and evaluate drying forces and their direction, acting upon hygroscopic materials across varied ambient conditions. This inconsistency reveals fundamental flaws in the E^3 metric's applicability and reliability across the diverse conditions encountered in water damage restoration. The E^3 formula appears to give little consideration to factors such as: external conditions, material temperatures, assemblies, or vapor pressure differentials between the materials, as well as external conditions and the ambient air within the drying environment(s).

Readers of this rebuttal are urged to complete their own evaluation of the E^3 metric, consult published resources, known industry experts, and conduct their own testing and analysis based on applications directly relevant to the restorative drying industry. Due diligence should be exercised before accepting or promoting new products, systems, or metrics such as E^3 in the water damage restoration industry.

3. Background

The E^3 formula utilizes unique enthalpy metrics, such as 'Dew Point Sensible Energy,' 'Dew Point Latent Energy,' 'Wet Bulb Latent Energy,' 'Wet Bulb Sensible Energy,' 'Dew Point Humidity Ratio,' and 'Wet Bulb Humidity Ratio’. These terms are absent from published studies, established scientific study, and seem to be exclusive to the author's work.

The dynamics of evaporation from hygroscopic materials have been extensively researched and are well understood by the relevant subset of the scientific community. There are numerous theoretical models that can predict the drying rates of a diverse array of hygroscopic materials under controlled conditions, with high accuracy. This understanding is supported by a wealth of studies that elucidate the physics and kinetics of evaporation, both from liquid water and from various hygroscopic materials. These studies often focus on the molecular dynamics involved

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[3] Ibid, pp. 4-5.

[4] Ibid, pp. 8-9.

when water molecules dissociate from materials, a subject extensively explored in the works of Arun S. Mujumdar. For further reference, please consult the appendix, which lists a number of peer-reviewed publications.

One seminal work in this field is the "Handbook of Industrial Drying (4th ed.)," a comprehensive 1301-page document peer-reviewed by international experts. This handbook includes chapters specifically dedicated to various industries involved in drying processes, but notably excludes complete assemblies of building materials found in the built environment. Some of the key sections include:

- Drying of diverse substances ranging from foodstuffs and pharmaceutical products to fibrous materials and biofuels.
- Specific chapters on the drying of grains, fruits, vegetables, herbal medicines, nanosize products, ceramics, peat, wood, minerals, wastewater treatment sludge, biotechnological products, coated webs, polymers, enzymes, and coal.
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- *Czesław Strumiłło, Peter L. Jones, and Romuald Żyłła*, Energy Aspects in Drying..1077
- *Stefan Jan Kowalski and Andrzej Rybicki*, Thermo-Hydro-Mechanical Aspects of Drying.............................1239

These referenced industries generally involve the drying of hygroscopic materials in batches with consistent moisture contents, under controlled conditions. This extensive body of research demonstrates a deep and nuanced understanding of the drying of materials, an understanding that is critical when evaluating the efficacy and applicability of new proposed metrics such as E^3 in the context of building materials and water damage restoration.

Contrastingly, the water damage restoration industry faces conditions that are markedly different from those outlined in the aforementioned research. Restoration projects often deal with a diverse array of wet materials which exhibit varied levels of moisture sorption, and demonstrate different penetration depths into thicker materials or assemblies. The built environment encompasses materials and assemblies with a broad spectrum of diffusivity characteristics and permeability factors, which can significantly influence surface evaporation. Moreover, finish materials in these environments vary greatly, each with unique permeability ratings, affecting the rate of evaporation from the interior of the material or assembly.

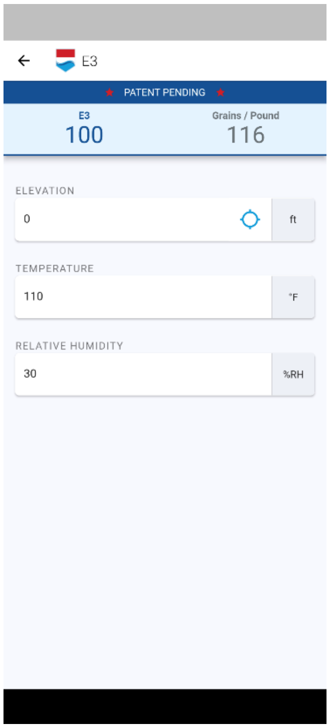
In the realm of restorative drying, conditions are rarely constant and are seldom identical across different projects due to many influencing variables. Certain elements contribute to the often observed, moderately variable conditions during a structural drying project. These elements include the differing rates of evaporation, the heat of condensation, occupant activity, the use of electrical appliances and equipment, and the influence of both radiant and ambient external conditions outside the drying chamber.

4. Rebuttal to validity of E^3 Formula against Dewald's claims — Fixed E^3 Analysis

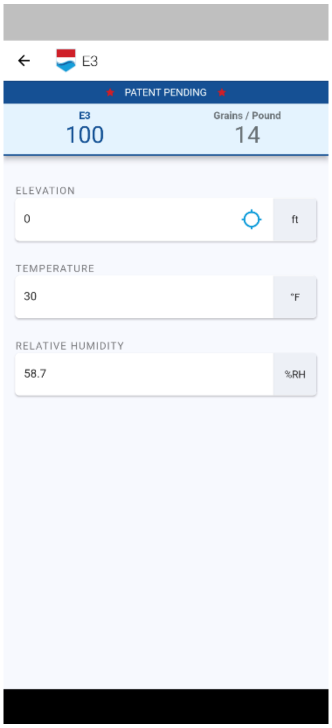
The author asserts the potential value of a singular metric (E^3) in the restoration industry that would quantify ambient air to deliver a "proportionate drying or evaporation rating." The author posits that such a "proportionate metric" could simplify complexities encountered in typical drying projects. However, for a metric to be deemed a reliable indicator of the relative drying rate, it must withstand rigorous mathematical and scientific scrutiny. Specifically, it should proportionally increase or decrease its values (relative rate) in response to variations in given ambient air conditions.
In assessing the validity of the E^3 formula against the author's claims, it is imperative to recognize that for a "proportionate metric" (sic)[5] to be deemed valid, identical metric values across various conditions should correspond to a similar rate of drying for common hygroscopic materials in the built environment.

Following is a table of E^3 values, derived from the E^3 app, version 2.4.5 +105, where all conditions produce the same E^3 value of 100 with an input elevation of 0'. Screenshots of the high and low values are provided.

Temperature (^{0}F)	Relative Humidity (%)	E^3
110	30	100
100	32.2	100
90	34.5	100
80	37.2	100
70	40.2	100
60	43.7	100
50	47.7	100
30	58.7	100



E3 100
Grains / Pound 116
ELEVATION 0 ft
TEMPERATURE 110 °F
RELATIVE HUMIDITY 30 %RH



E3 100
Grains / Pound 14
ELEVATION 0 ft
TEMPERATURE 30 °F
RELATIVE HUMIDITY 58.7 %RH

For E^3 to be a proportionate metric, these conditions above must have a reasonable expectation of drying hygroscopic materials at the same rate. In the example above, an atmospheric condition of

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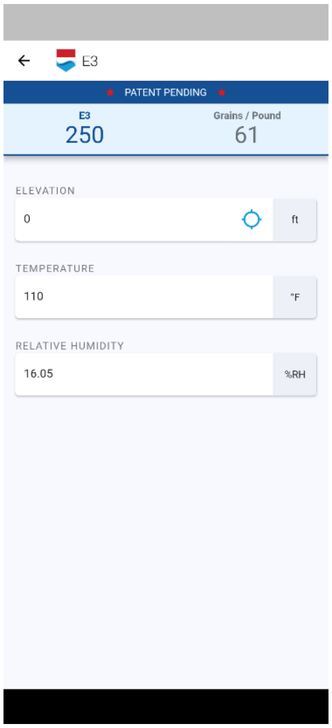
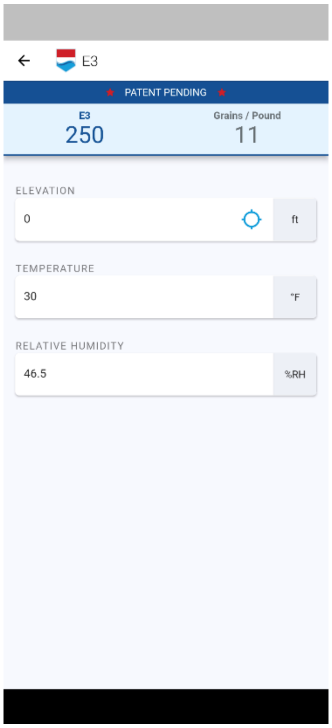
[5] "Proportional" often refers to a mathematical or consistent ratio relationship, while "proportionate" is more about the balance or fairness of the size or quantity in relation to something else.

60^{0}F 43.7 % RH would need to provide the same drying results as 100^0 F 32.2 % RH. Readers of this rebuttal are urged to evaluate these conditions against their individual knowledge and project data to determine whether or not E^3 can represent a proportionate drying rate metric. This peer-reviewed industry rebuttal paper proposes that, unless material temperatures are controlled independently, there are no known scenarios in which the above conditions could be expected to produce similar drying rates on hygroscopic materials, either in constant or falling rate drying, or with bound or free water.

Following is a table of E^3 values, derived from the E^3 app, version 2.4.5 +105, where all conditions produce the same E^3 value of 250 with an input elevation of 0’. Screenshots of the high and low values are provided. This indicates that the noted issues exist across a range of E3 values.

Temperature (^{0}F)	Relative Humidity (%)	E^3
110	16.05	250
100	17.7	250
90	19.65	250
80	22	250
70	24.8	250
60	28.25	250
50	32.65	250
30	46.5	250


E3
PATENT PENDING
E3 250
Grains / Pound 61
ELEVATION
0 ft
TEMPERATURE
110 °F
RELATIVE HUMIDITY
16.05 %RH


E3
PATENT PENDING
E3 250
Grains / Pound 11
ELEVATION
0 ft
TEMPERATURE
30 °F
RELATIVE HUMIDITY
46.5 %RH

4.1 Fixed Relative Humidity Analysis

Another evaluation to verify validity of a proportionate drying metric is to compare a set of known conditions where drying forces/rates are known to increase and evaluate whether the metric increases proportionately.

With a fixed relative humidity value of ambient air, increasing temperature will increase the rate of evaporation in hygroscopic materials fully exposed to said ambient air. The kiln drying industry is a noteworthy example of this, where lumber is frequently dried at elevated temperatures, but similar (or higher) relative humidity values as compared to the restoration industry. Additionally, as temperature increases with a fixed relative humidity, the equilibrium moisture content of hygroscopic materials universally decreases. This means that a material at equilibrium at a lower temperature will experience net drying (i.e., drying forces) when moved to a condition of higher temperature with the same relative humidity.

The chart below highlights how at 30%RH, the EMC value for wood decreases from 6.3 to 4.8 as the temperature moves from 30F to 150F.[6]

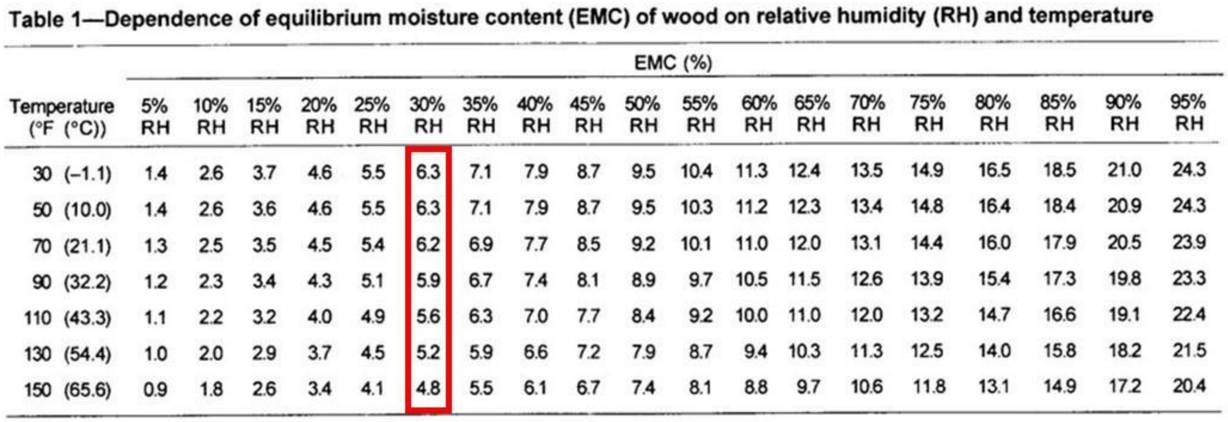


Table 1—Dependence of equilibrium moisture content (EMC) of wood on relative humidity (RH) and temperature

Temperature (°F (°C))	EMC (%)																		
	5% RH	10% RH	15% RH	20% RH	25% RH	30% RH	35% RH	40% RH	45% RH	50% RH	55% RH	60% RH	65% RH	70% RH	75% RH	80% RH	85% RH	90% RH	95% RH
30 (–1.1)	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.4	13.5	14.9	16.5	18.5	21.0	24.3
50 (10.0)	1.4	2.6	3.6	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.3	11.2	12.3	13.4	14.8	16.4	18.4	20.9	24.3
70 (21.1)	1.3	2.5	3.5	4.5	5.4	6.2	6.9	7.7	8.5	9.2	10.1	11.0	12.0	13.1	14.4	16.0	17.9	20.5	23.9
90 (32.2)	1.2	2.3	3.4	4.3	5.1	5.9	6.7	7.4	8.1	8.9	9.7	10.5	11.5	12.6	13.9	15.4	17.3	19.8	23.3
110 (43.3)	1.1	2.2	3.2	4.0	4.9	5.6	6.3	7.0	7.7	8.4	9.2	10.0	11.0	12.0	13.2	14.7	16.6	19.1	22.4
130 (54.4)	1.0	2.0	2.9	3.7	4.5	5.2	5.9	6.6	7.2	7.9	8.7	9.4	10.3	11.3	12.5	14.0	15.8	18.2	21.5
150 (65.6)	0.9	1.8	2.6	3.4	4.1	4.8	5.5	6.1	6.7	7.4	8.1	8.8	9.7	10.6	11.8	13.1	14.9	17.2	20.4

The graph following, from Chanpet et al. displays mass transfer coefficients (drying rates) which demonstrates that increasing temperature at a fixed relative humidity value also increases the mass transfer coefficient (drying rate) for rubberwood. (Rubberwood is a hardwood derived from the rubber tree and possesses typical hardwood qualities. It does not possess any unique properties like the bark of the rubber tree.)[7]

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[6] Simpson, William T. (1998). Equilibrium Moisture Content of Wood in Outdoor Locations in the United States and Worldwide, p. 3.

[7] Chanpet, Malisa; Rakmak, Nirattisai; Matan, Nirundorn; and Siripatana, Chairat. “Effect of air velocity, temperature, and relative humidity on drying kinetics of rubberwood.” Heliyon, (2020).

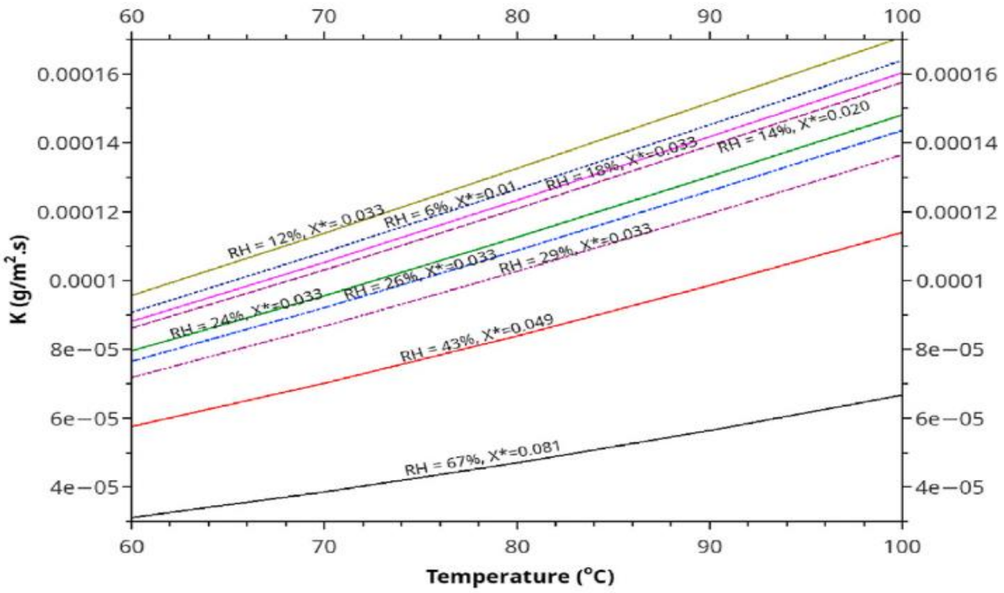


Figure 12. The combined effect of temperature and %RH on the overall mass transfer coefficient as calculated using the correlation developed in this work. The calculation is based on $e = 10$ mm and $V = 3.5$ m/s.

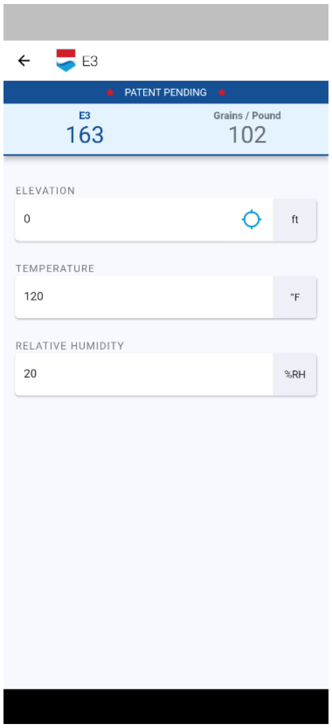
Source: Chanpet, Malisa; Rakmak, Nirattisai; Matan, Nirundorn; and Siripatana, Chairat. “Effect of air velocity, temperature, and relative humidity on drying kinetics of rubberwood.” Heliyon, (2020).

The x-axis in the above graph is temperature, the y-axis is a mass transfer coefficient utilized in the model equation that Chanpet Et al, chose for their study. This mass transfer coefficient, with a unit in “mass per area per second” correlates to a drying rate.

The E^3 metric exhibits incorrect scaling under varying temperature scenarios while maintaining a constant relative humidity level. This failure is evident when contrasting the E^3 metric's response to the drying influence of elevated temperatures, as per the Wood Equilibrium Moisture Content (EMC) chart developed by the U.S. Department of Forestry. In conditions where temperature rises while relative humidity remains fixed, a decrease in the E^3 metric is observed, which paradoxically indicates less favorable outcomes. This discrepancy highlights a fundamental flaw in the E^3 metric's ability to provide a proportional drying or evaporation rate.

Following is a table of E^3 values, derived from the E^3 app, version 2.4.5 +105, where the relative humidity was fixed at 20% across multiple temperatures. Values were based on an elevation of 0’ (sea level). Screenshots of the high and low values are provided.

Temperature (^{0}F)	Relative Humidity (%)	E^3
120	20	163
100	20	209
80	20	293
60	20	539
50	20	958
40	20	970

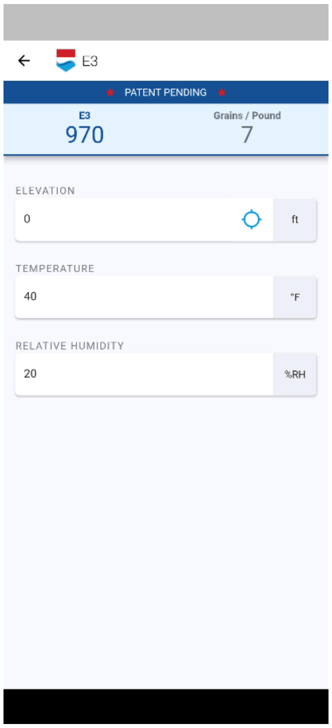


E3 163
Grains / Pound 102

ELEVATION 0 ft

TEMPERATURE 120 °F

RELATIVE HUMIDITY 20 %RH



E3 970
Grains / Pound 7

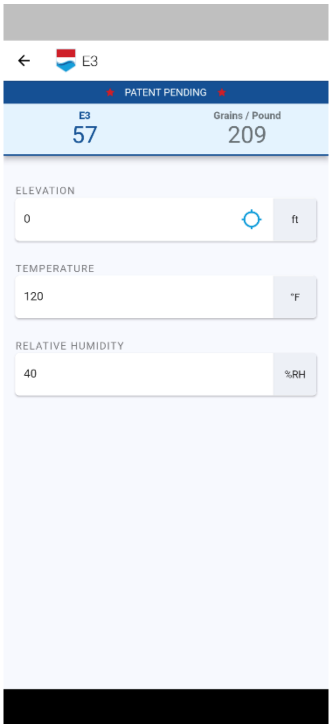
ELEVATION 0 ft

TEMPERATURE 40 °F

RELATIVE HUMIDITY 20 %RH

Following are two more tables at 40% RH and 60% RH which confirm that this trend exists across all relative humidity values and not just 20% RH.

Temperature (^{0}F)	Relative Humidity (%)	E^3
120	40	57
100	40	69
80	40	87
60	40	121
50	40	153
40	40	222



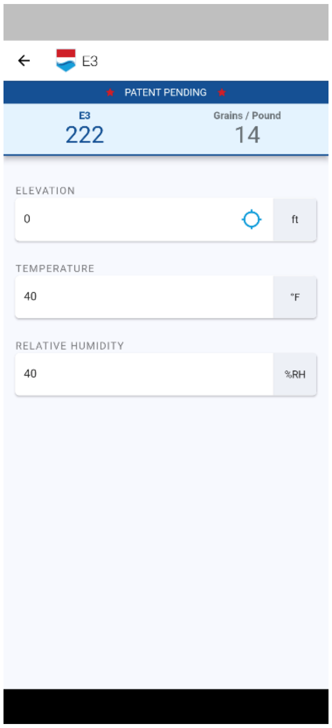
E3 57

Grains / Pound 209

ELEVATION 0 ft

TEMPERATURE 120 °F

RELATIVE HUMIDITY 40 %RH



E3 222

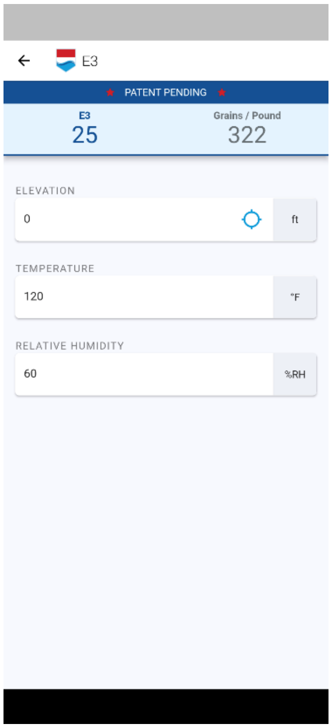
Grains / Pound 14

ELEVATION 0 ft

TEMPERATURE 40 °F

RELATIVE HUMIDITY 40 %RH

Temperature (°F)	Relative Humidity (%)	E^3
120	60	25
100	60	29
80	60	35
60	60	46
50	60	54
40	60	67

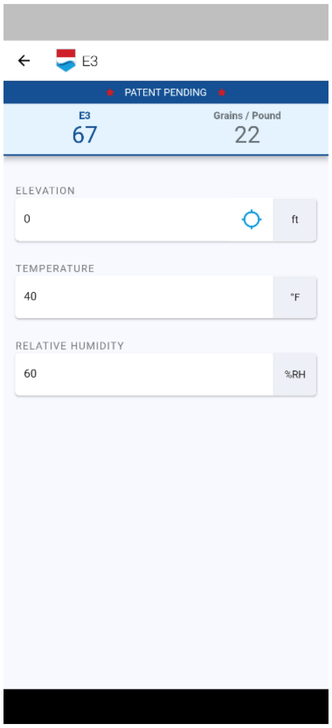


E3 25 Grains / Pound 322

ELEVATION 0 ft

TEMPERATURE 120 °F

RELATIVE HUMIDITY 60 %RH



E3 67 Grains / Pound 22

ELEVATION 0 ft

TEMPERATURE 40 °F

RELATIVE HUMIDITY 60 %RH

4.2 Kiln Drying Comparison

Below is a wood kiln drying schedule from the U.S. Dept of Forestry. (Dry Kiln Schedules for Commercial Woods Temperate and Tropical. U.S. Dept of Agriculture. Forest Service. General Technical Report FPL- GTR-57, p. 132)

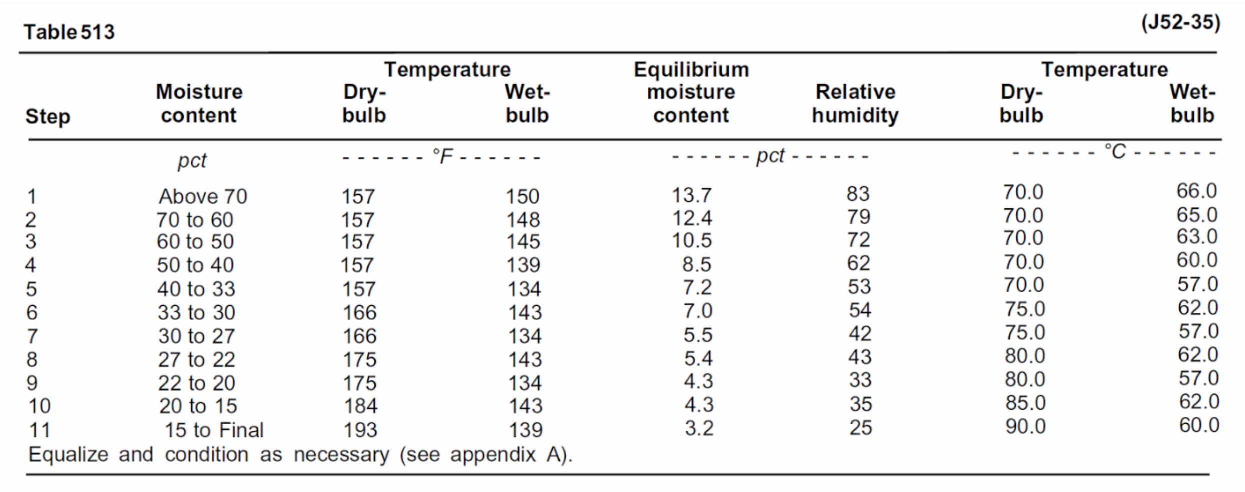


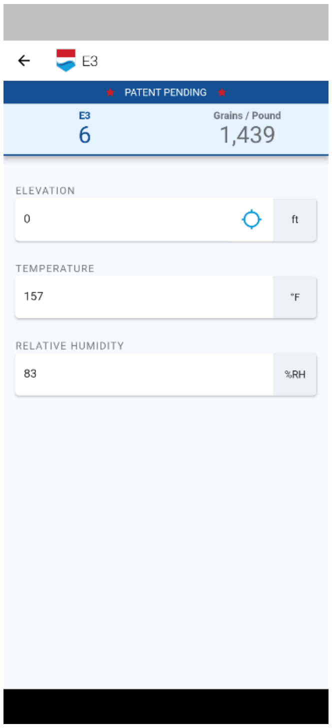
Table 513 **(J52-35)**

Step	Moisture content	Temperature Dry-bulb	Wet-bulb	Equilibrium moisture content	Relative humidity	Temperature Dry-bulb	Wet-bulb
	pct	°F	°F	pct	pct	°C	°C
1	Above 70	157	150	13.7	83	70.0	66.0
2	70 to 60	157	148	12.4	79	70.0	65.0
3	60 to 50	157	145	10.5	72	70.0	63.0
4	50 to 40	157	139	8.5	62	70.0	60.0
5	40 to 33	157	134	7.2	53	70.0	57.0
6	33 to 30	166	143	7.0	54	75.0	62.0
7	30 to 27	166	134	5.5	42	75.0	57.0
8	27 to 22	175	143	5.4	43	80.0	62.0
9	22 to 20	175	134	4.3	33	80.0	57.0
10	20 to 15	184	143	4.3	35	85.0	62.0
11	15 to Final	193	139	3.2	25	90.0	60.0

Equalize and condition as necessary (see appendix A).

Below is a chart of E^3 values at each of the kiln drying conditions derived from the E^3 app, version 2.4.5 +105 with the elevation set to 0

Temperature (^{0}F)	Relative Humidity (%)	E^3
157	83	6
157	79	8
157	72	12
157	62	18
157	53	26
166	54	24
166	42	39
175	43	36
175	33	54
184	35	48
193	25	72



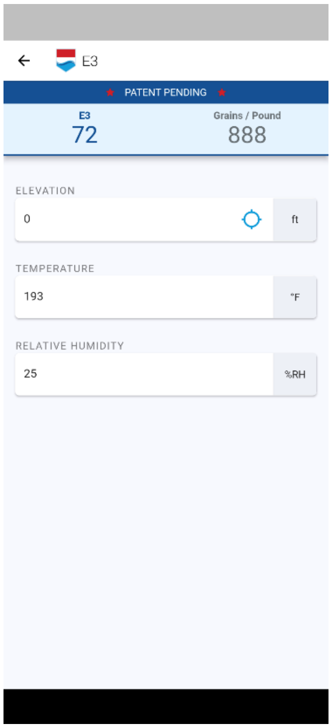
E3 6

Grains / Pound 1,439

ELEVATION 0 ft

TEMPERATURE 157 °F

RELATIVE HUMIDITY 83 %RH



E3 72

Grains / Pound 888

ELEVATION 0 ft

TEMPERATURE 193 °F

RELATIVE HUMIDITY 25 %RH

Compare the following conditions

	Temp (^{0}F)	RH (%)	Humidity Ratio	Dew Point(F)	EMC (%)	E^3
Condition 1	193	25	889gpp	134	3.2%	72
Condition 2	80	22	33gpp	38	~4.7%	250

Condition 1 is from the previous kiln drying schedule, representing the schedule's most aggressive condition utilized to dry lumber to final conditions with moisture contents lower than 15%. With an EMC of 3.2, this condition is capable of drying lumber to any threshold needed for building construction.

Condition 2 is a reference condition within any reasonable ranges one may anticipate encountering in the restorative drying industry.

For E^3 to be a proportional metric, when comparing two conditions, the condition with a higher E^3 must be expected to dry materials at a rate approximately equal to the ratio of the two conditions.

For Condition 1 and Condition 2 above, this would mean the relative drying rate for Condition 2 would be 250/72, or 3.47. Condition 2 would need to dry materials 3.47 times faster than Condition 1 for the author's claims to be validated.

Readers of this rebuttal are urged to consider whether there are any circumstances where Condition 2 could be expected to outperform Condition 1, let alone by a factor of 3.47.

5. Rebuttal to E^3 vs. Blaylock Study Data

In his comparison of E^3 values with findings from Jerry Blaylock's 2017 study, Dewald omits pertinent disclosures about their prior professional interactions. These include joint ownership of the American Drying Institute in Morristown, Tennessee, and their collaboration as co-inventors on a patent application filed in 2009 (USPTO Publication #2009/0095056 A1). This patent publication includes claims for a method for assessing "evaporation rate potentials" in ambient air.

Furthermore, Dewald does not address a critical issue regarding these past associations and the timing of Blaylock's study. It raises the question of whether Dewald was unaware of Blaylock's data during the E^3 formula's development, or if there was a possibility that Blaylock's findings influenced the E^3 formula. If the latter is true, and the Blaylock data was referenced in developing the E^3 formula, the data cannot be considered for validation by "third-party testing".[8]
Addressing the concerns about the legitimacy of comparing E^3 values with data from the Blaylock study, it's crucial to recognize that the dataset from Blaylock's research is insufficient for making such a comparison.

The original publication by Blaylock[9] does not assert the same level of claims about the data as those made by Dewald. It is important to emphasize that Blaylock's work underwent peer review before publication.

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[8] Ibid, p. 24.

[9] Blaylock, J. (2015). An Examination of the Role of Vapor Pressure and Enthalpy in Drying Water-Damaged Structures Containing Wood-Based Products. In *Wood Design Focus*, 25(2), p. 17.

In Blaylock's study, the materials used did not share uniform initial moisture content, and Dewald's analysis did not incorporate any adjustments to account for this discrepancy. Blaylock's study, as well as Dewald's interpretation of it, lacks a defined objective or end goal for the drying process. Data points were only recorded at the commencement of the experiment (T = 0 hours) and after 24 hours (T = 24 hours) with no intermediate data provided at regular intervals. Drying rates of hygroscopic materials vary based on moisture content and a relative comparison of drying rates can only be made if drying times for the same moisture content range are measured.

In Blaylock's study, the materials used were not equilibrated to ambient temperature prior to the start of the experiment. No data was presented for the materials as they changed temperature, this data would be key in being able to apply a meaningful comparison to Dalton's law of evaporation. Without this data, any comparison to Dalton's law of evaporation is incomplete.

It is important to note that Dewald's claim of accuracy in correlating drying rates with E^3 values is limited to the findings at T = 24 hours. Beyond this point, specifically from immediately after T = 24 hours as the materials trend towards their equilibrium moisture content, the accuracy of this correlation begins to diminish, with the eventual result being significantly diminished accuracy.

The following data is presented to demonstrate that the accuracy claims made by Dewald only exist at the T=24 hours' time. This paper does not endorse this methodology to evaluate such metrics because as previously stated, corrections were not made for varying moisture content levels and drying evaluated over defined ranges.

	Temp (^{0}F)	RH (RH)	E^3	EMC (%)	Av. T=0 %MC	Av. T=24hr %MC	Av. Final %MC	(T=0 %) - (T=24 %)	(T=0 %) - (Final %)
Condition 1	70	35	131	6.9	23.7	13.2	6.9	10.5%	16.8%
Condition 2	90	25	171	5.1	24.2	10.5	5.1	13.7%	19.1%
Condition 3	115	17.3	211	3.5	26.5	9.5	3.5	17%	23%

	E^3	E^3 Ratio to Cond. 1	“progress” at T-24hr	“progress” ratio at T=24hr compared to condition 1	T=24hr Error Rate (Progress Ratio – E^3 Ration) / E^3 Ratio	Final Prog	Final Cond. / Cond. 1	Final Cond. Error Rate
Cond. 1	131	1	10.5%	1	na	16.8%	1	na
Cond. 2	171	1.305	13.7%	1.305	~0%	19.1%	1.137	12.9%
Cond. 3	211	1.611	17%	1.619	.5%	23%	1.369	15%

As T (time) increases, and the materials trend towards the EMC for each of the three conditions, the error of the E^3 prediction increases substantially.

The final error rate for Condition 2 vs Condition 1 is 12.9% compared to ~0% at T=24hr.

The final error rate for Condition 3 vs Condition 1 is 15% compared to .5% at T=24hr.

This results in an average error rate of ~14% as compared to the error rate of ~.25% presented at T-24hr.

This comparison is not provided to affirm any accuracy claims for E^3, but to emphasize that any study comparing relative drying rates must be controlled for similar moisture content ranges. Without a defined starting moisture content, ending moisture content, and time taken to accomplish that given amount of “drying,” any comparison of relative drying rates between ambient conditions is inconclusive.

6. Temperature Discontinuity Study Evaluation

Dewald compares E^3 values and comparative evaporation rates in two comparisons, “Comparison 1” and “Comparison 2” against a peer-reviewed publication that evaluated the phenomena of measured “temperature discontinuities at an evaporating interface”.[10] This is a complex phenomenon noted in many academic studies in which the measured temperature of liquid water at the evaporative interface does not directly correlate with the measured temperature of the vapor at the evaporative interface. In theory, these two temperatures should converge to the same value as the distance from the evaporative interface decreases for both the liquid and vapor.

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[10] Dewald, Enthalpy Evaporation Evaluation – A Case for the E3 Drying Metric white pages, p. 6.

The experimental conditions employed in these laboratory studies are not reflective of the environments typically encountered within the restoration industry. The experiments were conducted under significant vacuum pressures, ranging from 176 pascals to 913 pascals, in stark contrast to the normal atmospheric pressure of approximately 101,000 pascals. To put this into perspective, the atmospheric pressure at an altitude of 65,000 feet is about 1500 pascals. The experiments were thus performed in conditions ranging between 0.002 and 0.009 atmospheres, 0.2% through 0.9% of the pressure at sea level. Many of these experiments were conducted at temperatures and pressures below the triple point of water, which is the condition in which vapor, liquid, and solid water can exist at the same time, approximately .006atm and 32.1F. In such vacuum chambers, the concept of "ambient air" is virtually non-existent. Jafari et. al treat the vacuum pressure of the chamber and vapor pressure of the water as equal, given the absence of other significant partial pressures.[11]

280 *V.K. Badam et al. / Experimental Thermal and Fluid Science 32 (2007) 276–292*

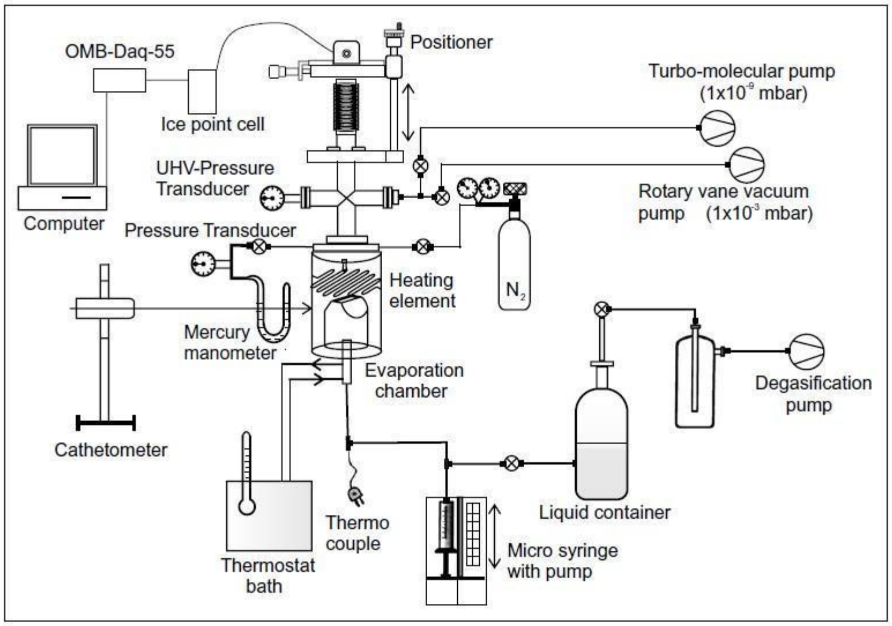

Fig. 1. Schematic diagram of the experimental setup as described by Popov et al. [35] with modified liquid channel and heating element.

Above is a diagram of the experimental setup utilized in one of the underlying studies.
In the referenced laboratory experiments, the temperature measurements for both liquid water and the air above it were not taken from the bulk fluids but rather from positions ranging from 3mm to less than 1mm from the evaporating surface.[12] Dewald asserts that E^3 determines a relative drying rate based on the temperature and humidity of the bulk air mass or "ambient air," not based on conditions at the evaporating surface within the temperature and humidity gradients. Gradients exist between the bulk air mass and the evaporating surface, where conditions progressively align

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[11] Jafari, P. Amritkar, A and Ghasemi, H. "Temperature Discontinuity at an Evaporating Water Interface." https://pubs.acs.org/JPCC (2019).

[12] Popov, S., Melling, A., Durst, F. & Ward, C. A. Apparatus for investigation of evaporation at free liquid-vapour interfaces. Int. J. Heat and Mass Transfer 48, 2299–2309 (2005).

with those of the water at or on the surface as proximity to this surface decreases. Both temperature and vapor pressure should exhibit this gradient, in accordance with the fundamental laws of physics.

The paper cited by Dewald discusses the phenomenon of measured temperature discontinuity at an evaporating surface, arguing that these measurements are significantly influenced by boundary conditions on the vapor side of the interface and do not accurately represent the state at the interface: ***“we demonstrated that the measured discontinuities were strongly affected by boundary conditions on the vapor side of the interface and do not reflect the interfacial state**.”*[13] *(emphasis added)*

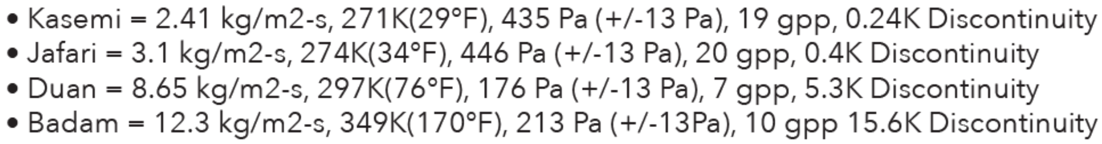
In his paper, Dewald states: “As mentioned by the authors of this study, to have a chance at predictable modeling for evaporation the temperature difference between the liquid and bulk vapor phase must be compensated for. This is what I did in the above calculations. A correction calculation was made by dividing the free water E^3 value by the temperature discontinuity; essentially providing an E^3 per one degree value.”[14] Dewald’s “corrections” for temperature discontinuity in his analysis are misguided, as the paper he cites concludes that the phenomenon is attributed to a measurement error rather than actual conditions. Furthermore, Dewald neither provides a logical explanation, nor scientific evidence to justify the correction for “each degree” of temperature discontinuity.

6.1 Comparison 1

In Dewald’s first comparison to data presented in the cited paper, one chart and one diagram are cited on page 7. Dewald then states what data the analysis will include and also specifies that only half of the full E^3 calculation will be utilized as these experiments are being done on “Free Water”.

“We will evaluate their test data in two ways. First let’s look at what the **average evaporation** rate was from the liquid in the different tests, the **average bulk vapor temperatures**, (emphasis added) and vapor pressure (humidity ratio) values, as well as the temperature discontinuity values:” [15]

Dewald then lists this data:



- Kasemi = 2.41 kg/m2-s, 271K(29°F), 435 Pa (+/-13 Pa), 19 gpp, 0.24K Discontinuity
- Jafari = 3.1 kg/m2-s, 274K(34°F), 446 Pa (+/-13 Pa), 20 gpp, 0.4K Discontinuity
- Duan = 8.65 kg/m2-s, 297K(76°F), 176 Pa (+/-13 Pa), 7 gpp, 5.3K Discontinuity
- Badam = 12.3 kg/m2-s, 349K(170°F), 213 Pa (+/-13Pa), 10 gpp 15.6K Discontinuity

The above data does not correlate with the cited data table.

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[13] Jafari, et al, p. 1.
[14] Dewald, p. 9.
[15] Dewald, p. 8.

The values listed as averages do not match the averages of those values. Instead, the above data partially matches that which is listed in the first paragraph of page 4 of the cited publication.[16]

From the citation below, referencing individual experimental data sets rather than averages, the mass flux values match Dewald's reported values, as do the vapor pressure values and temperature discontinuity values. However, T_B the temperature at the 3mm boundary or "bulk vapor temperature" values are not specified in this citation. It appears Dewald utilized average values from the cited data table rather than values attributable to these specific individual experiments. Dewald or did not provide any direct support for the values used for T_B in the analysis.

"Kazemi et al. measured temperature discontinuity of ***0.24 K*** *at vapor pressure of* ***435 Pa*** *and mass flux of* ***2.41x10^{-4} kg/(m2s)****. In the experiments, there was no heating element in the vapor phase. Jafari et al.15 measured temperature discontinuity of* ***0.4 K*** *at* ***446 Pa*** *and evaporative mass flux of* ***3.1x10^{-4} kg/(m2s)****. In this experiment, the liquid container was mounted on a heating stage with a temperature of 40, to increase heat flux to the interface. Similar to Kazemi et al.,[20] there was no heating element in the vapor side of the interface. In a work by Duan et al.[38] on water evaporation with vapor pressure of* ***176 Pa*** *and the mass flux was* ***8.65x10^{-4} kg/(m2s)****, interfacial temperature discontinuity of* ***5.3 K*** *was reported. In these studies, the liquid bottom was kept at 277 K to suppress buoyancy convection. Badam et al.[17] reported even greater interfacial temperature discontinuity of* ***15.6****. for the case of* ***213 Pa*** *vapor pressure* ***and 12.3x10^{-4} Kg/(m2s)*** *evaporative mass flux. In this experiment, a heating element was mounted on the vapor side at coordinate of 3 mm above the liquid-vapor interface to boost heat flux to the liquid-vapor interface."* (emphasis added)[17]

One of the four experiments has no additional heat applied to the system, one has the bottom temperature of the liquid held constant, one has heat applied to part of the liquid transport system, and one has heat applied 3mm off the surface in the vapor. These experiments were not concluded in a manner as to facilitate the predictive evaporation rates between them, nor would any comparison have significant merit.

Dewald also fails to address how any of these values were extrapolated to "gpp" values given the vacuum pressures present. Presumably, these gpp values were derived through reference conditions (including temperature, relative humidity, and altitude/pressure) for which the E^3 values were calculated, though none of these calculations or values are declared.

It is important to note that the T_B values for these conditions are not the values utilized in calculating temperature discontinuity. Temperature discontinuity is calculated by taking the difference between the liquid and vapor at the interface, not the vapor 3mm above the interface. Dewald "corrects" for temperature discontinuity despite the fact that the E^3 values appear to be calculated based off of T_B values, rather than the temperature at the interface. If the E^3 calculation is designed to evaluate conditions of the bulk air mass, applying a correction for temperature discontinuity (either real, or simply measurement error) is erroneous. Under any other

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[16] Jafari, et al, p. 4.

[17] Kazemi, Mohammad Amin; Nobes, David S. and Elliott, Janet A. W. "Experimental and Numerical Study of the Evaporation of Water at Low Pressures," American Chemical Society, (2017), Vol. 33, p. 4587.

circumstance, the two temperature values utilized to calculate temperature discontinuity would be unknown and unless these values are a component of the E^3 formula, correcting for them is inappropriate.

Readers of this rebuttal should take note of the following fact. Of the four cited experiments, these are the temperature values for the surface of the liquid water at the evaporating interface: -4.52C, -4.2C, -16.15C, and -13.42C. The average value of these four is -9.6C, or 14.7F.

All four of these individual experiments were conducted at temperatures and pressures below the triple point of water, where absent the specific experimental conditions (e.g., heat flux to the liquid and mass flux from evaporation), liquid water would not be possible. Dewald fails to substantiate how extreme conditions such as this correlate to the restoration industry.

Given a lack of underlying information available, a corrected calculation against Dewald's claims is not presented in this rebuttal. Discrepancies that impact any accuracy claim have been noted, including the arbitrary correction of E^3 values "per degree" of temperature discontinuity. Regardless of any corrections for specific accuracy claims, these test conditions do not represent any meaningful analogy to the restorative drying industry.

6.1.1 Supporting Information in analysis of "Comparison 1" - "Kazemi"

The temperature listed for the single experiment (at 435.7pa and .24 temperature discontinuity) is -4.28C, which is 268.9K (24.3F).[18] Dewald lists 271K(29F) for this data which does not match. 271K however approximates the average T_B value from the "Kazemi" data from the cited table. This implies Dewald is utilizing one average value from a range of experiments in addition to three specific values cited from one underlying experiment. The other values are substantiated through the underlying studies data.

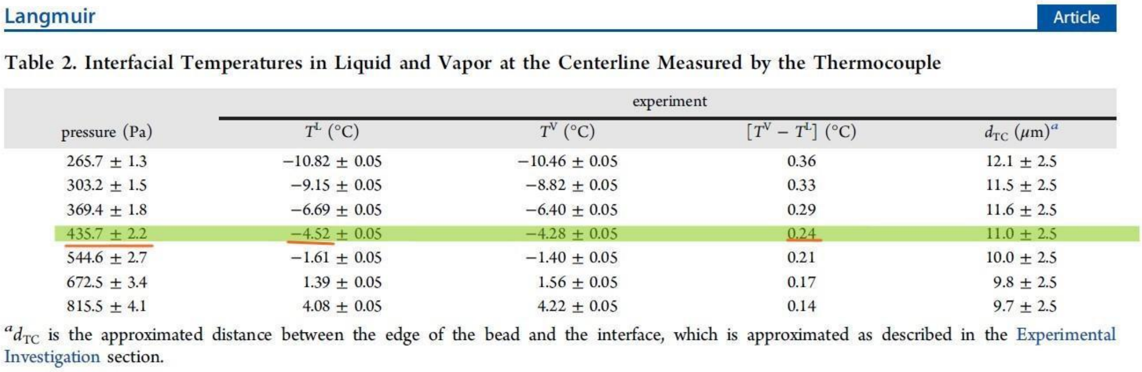

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Table 2. Interfacial Temperatures in Liquid and Vapor at the Centerline Measured by the Thermocouple

	experiment			
pressure (Pa)	T^L (°C)	T^V (°C)	$[T^V - T^L]$ (°C)	d_{TC} (μm)[a]
265.7 ± 1.3	−10.82 ± 0.05	−10.46 ± 0.05	0.36	12.1 ± 2.5
303.2 ± 1.5	−9.15 ± 0.05	−8.82 ± 0.05	0.33	11.5 ± 2.5
369.4 ± 1.8	−6.69 ± 0.05	−6.40 ± 0.05	0.29	11.6 ± 2.5
435.7 ± 2.2	−4.52 ± 0.05	−4.28 ± 0.05	0.24	11.0 ± 2.5
544.6 ± 2.7	−1.61 ± 0.05	−1.40 ± 0.05	0.21	10.0 ± 2.5
672.5 ± 3.4	1.39 ± 0.05	1.56 ± 0.05	0.17	9.8 ± 2.5
815.5 ± 4.1	4.08 ± 0.05	4.22 ± 0.05	0.14	9.7 ± 2.5

[a] d_{TC} is the approximated distance between the edge of the bead and the interface, which is approximated as described in the Experimental Investigation section.

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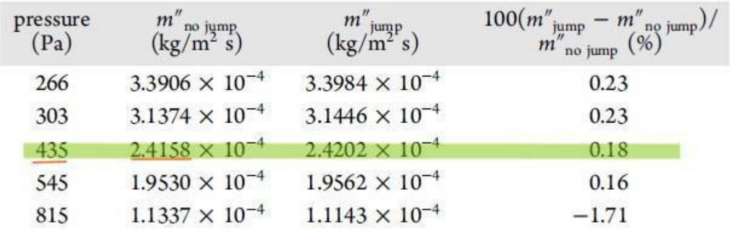
[18] Kazemi, Mohammad Amin; Nobes, David S. and Elliott, Janet A. W. "Experimental and Numerical Study of the Evaporation of Water at Low Pressures," American Chemical Society, (2017), Vol. 33, p. 4587.

Table 3. Comparison of the Evaporation Fluxes Calculated in the Simulation with and without the Temperature Jump at the Interface



pressure (Pa)	$m''_{\text{no jump}}$ (kg/m^2 s)	m''_{jump} (kg/m^2 s)	$100(m''_{\text{jump}} - m''_{\text{no jump}})/m''_{\text{no jump}}$ (%)
266	3.3906×10^{-4}	3.3984×10^{-4}	0.23
303	3.1374×10^{-4}	3.1446×10^{-4}	0.23
435	2.4158×10^{-4}	2.4202×10^{-4}	0.18
545	1.9530×10^{-4}	1.9562×10^{-4}	0.16
815	1.1337×10^{-4}	1.1143×10^{-4}	−1.71

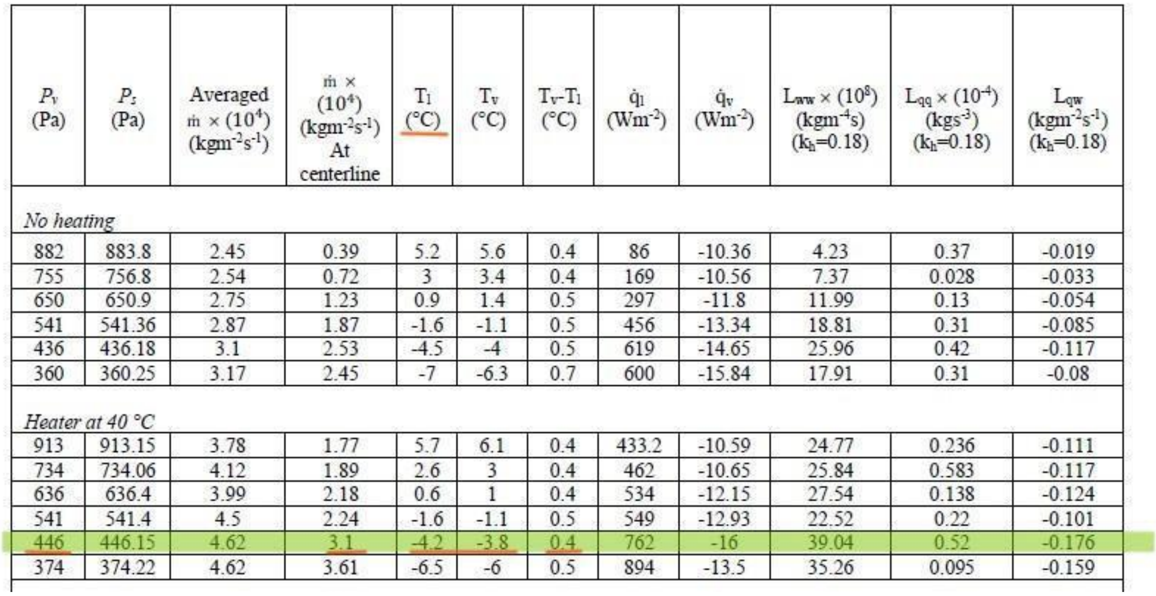
Note the temperature of the liquid water surface in this experiment is -4.52C.

"Jafari"

Per the previous citation, "*In this experiment, the liquid container was mounted on a heating stage with temperature of 40.*" This means that for this experiment the mass flux rate was boosted by heating the liquid.

Dewald lists 274K (34F) as the temperature of bulk vapor in this experiment. This value is unsubstantiated. The average value of the "Jafari" data from the table is 275.5k. It is unclear why Dewald utilized this value, which directly relates to subsequent accuracy claims. The other values are substantiated through the underlying studies data.

Table 2. Summary of evaporation experiment at different thermodynamic conditions



P_v (Pa)	P_s (Pa)	Averaged $\dot{m} \times (10^4)$ (kgm^{-2}s^{-1})	$\dot{m} \times (10^4)$ (kgm^{-2}s^{-1}) At centerline	T_l (°C)	T_v (°C)	T_v-T_l (°C)	$\dot{q}_l$ (Wm^{-2})	$\dot{q}_v$ (Wm^{-2})	$L_{ww} \times (10^8)$ (kgm^{-4}s) (k_h=0.18)	$L_{qq} \times (10^{-4})$ (kgs^{-3}) (k_h=0.18)	L_{qw} (kgm^{-2}s^{-1}) (k_h=0.18)
No heating											
882	883.8	2.45	0.39	5.2	5.6	0.4	86	-10.36	4.23	0.37	-0.019
755	756.8	2.54	0.72	3	3.4	0.4	169	-10.56	7.37	0.028	-0.033
650	650.9	2.75	1.23	0.9	1.4	0.5	297	-11.8	11.99	0.13	-0.054
541	541.36	2.87	1.87	-1.6	-1.1	0.5	456	-13.34	18.81	0.31	-0.085
436	436.18	3.1	2.53	-4.5	-4	0.5	619	-14.65	25.96	0.42	-0.117
360	360.25	3.17	2.45	-7	-6.3	0.7	600	-15.84	17.91	0.31	-0.08
Heater at 40 °C											
913	913.15	3.78	1.77	5.7	6.1	0.4	433.2	-10.59	24.77	0.236	-0.111
734	734.06	4.12	1.89	2.6	3	0.4	462	-10.65	25.84	0.583	-0.117
636	636.4	3.99	2.18	0.6	1	0.4	534	-12.15	27.54	0.138	-0.124
541	541.4	4.5	2.24	-1.6	-1.1	0.5	549	-12.93	22.52	0.22	-0.101
446	446.15	4.62	3.1	-4.2	-3.8	0.4	762	-16	39.04	0.52	-0.176
374	374.22	4.62	3.61	-6.5	-6	0.5	894	-13.5	35.26	0.095	-0.159

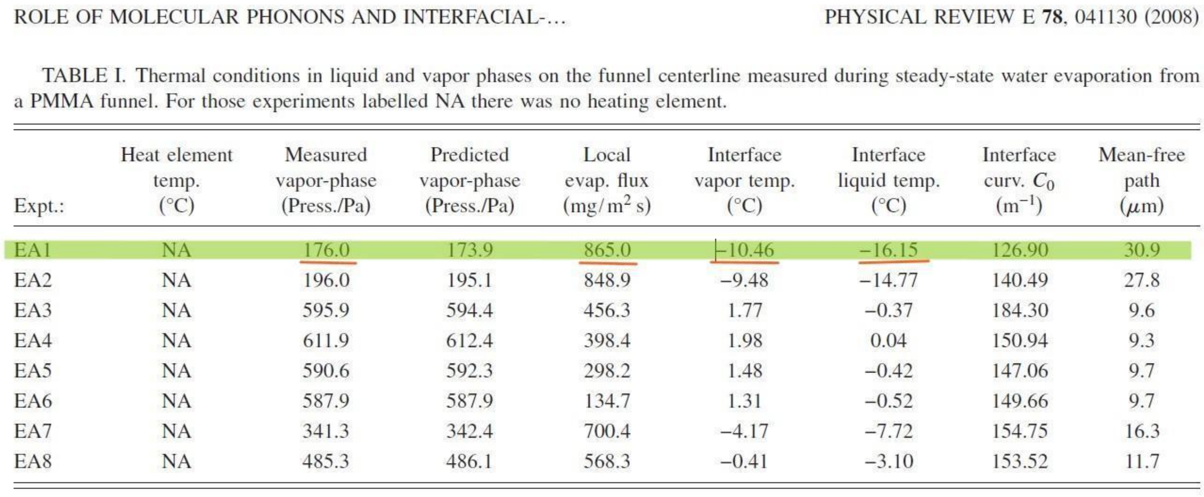
Note that the temperature of the liquid at the interface is -4.2C.

“Duan”

In this specific experiment some temperature control was applied, “*In these studies, the liquid bottom was kept at 277 K to suppress buoyancy convection.”*[19]

It appears the “Temperature Discontinuity Paper” may contain an error in this data, the mass flux values and vapor pressure match correctly, but the temperature discontinuity value appears to be actually 5.7C when it is listed as 5.3C.

Dewald claims the temperature of bulk vapor was 297K (76F). This does not correlate with the underlying studies’ data. However, the average T_B value for the “Duan” data in the table is 297.1K. It appears Dewald has used this average value alongside the specific data for a single experiment.



ROLE OF MOLECULAR PHONONS AND INTERFACIAL-… PHYSICAL REVIEW E **78**, 041130 (2008)

TABLE I. Thermal conditions in liquid and vapor phases on the funnel centerline measured during steady-state water evaporation from a PMMA funnel. For those experiments labelled NA there was no heating element.

Expt.:	Heat element temp. (°C)	Measured vapor-phase (Press./Pa)	Predicted vapor-phase (Press./Pa)	Local evap. flux (mg/m^2 s)	Interface vapor temp. (°C)	Interface liquid temp. (°C)	Interface curv. C_0 (m^{-1})	Mean-free path (μm)
EA1	NA	176.0	173.9	865.0	−10.46	−16.15	126.90	30.9
EA2	NA	196.0	195.1	848.9	−9.48	−14.77	140.49	27.8
EA3	NA	595.9	594.4	456.3	1.77	−0.37	184.30	9.6
EA4	NA	611.9	612.4	398.4	1.98	0.04	150.94	9.3
EA5	NA	590.6	592.3	298.2	1.48	−0.42	147.06	9.7
EA6	NA	587.9	587.9	134.7	1.31	−0.52	149.66	9.7
EA7	NA	341.3	342.4	700.4	−4.17	−7.72	154.75	16.3
EA8	NA	485.3	486.1	568.3	−0.41	−3.10	153.52	11.7

Note the liquid temperature in this experiment is -16.15C.

“Badam”

“In this experiment, a heating element was mounted on the vapor side at coordinate of 3 mm above the liquid-vapor interface to boost heat flux to the liquid-vapor interface.”

Dewald lists the temperature of the bulk vapor as 349K (170F). When in this specific experiment, the heating element is set to 80C which is 176F. It is unclear why Dewald chose this value which directly impacts accuracy claims.

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[19] Duan, Fei; Ward, Charles Albert; and Durst, F. “Role of molecular phonons and interfacial-temperature discontinuities in water evaporation,” (2014), p. 041130-3.

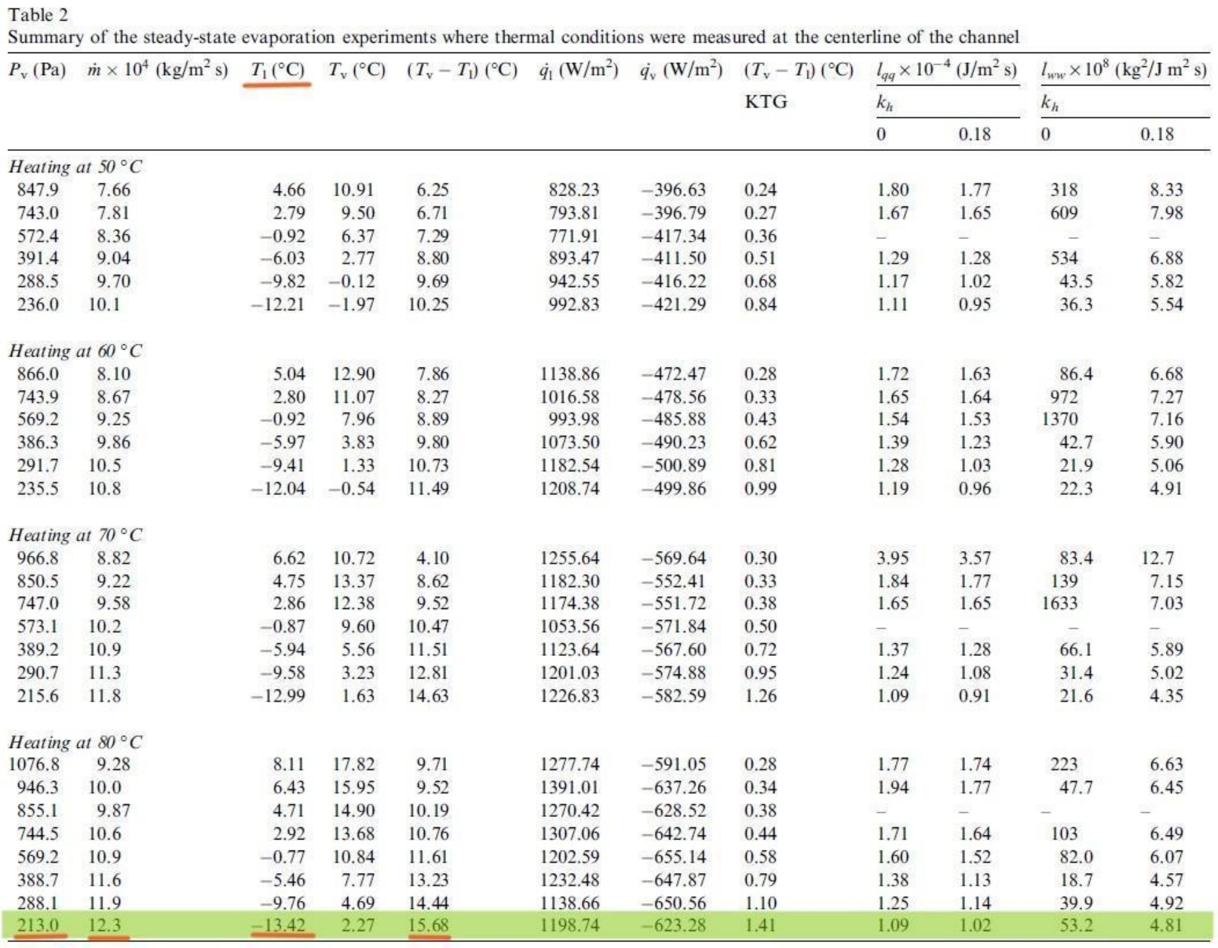


Table 2

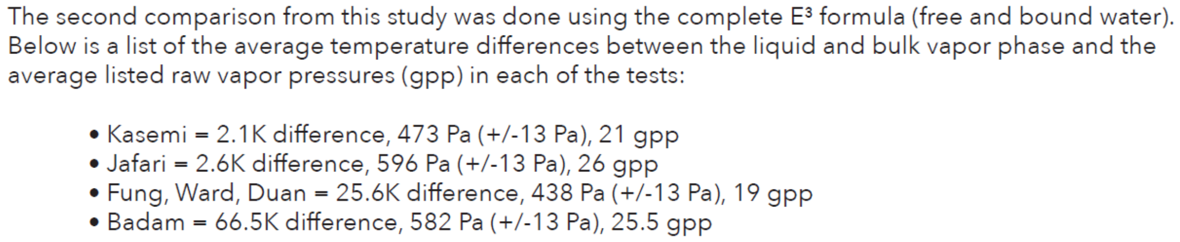
Summary of the steady-state evaporation experiments where thermal conditions were measured at the centerline of the channel

P_v (Pa)	$\dot{m} \times 10^4$ (kg/m^2 s)	T_l (°C)	T_v (°C)	$(T_v - T_l)$ (°C)	$\dot{q}_l$ (W/m^2)	$\dot{q}_v$ (W/m^2)	$(T_v - T_l)$ (°C)	$l_{qq} \times 10^{-4}$ (J/m^2 s)		$l_{ww} \times 10^8$ (kg^2/J m^2 s)	
							KTG	k_h		k_h	
								0	0.18	0	0.18
Heating at 50 °C											
847.9	7.66	4.66	10.91	6.25	828.23	−396.63	0.24	1.80	1.77	318	8.33
743.0	7.81	2.79	9.50	6.71	793.81	−396.79	0.27	1.67	1.65	609	7.98
572.4	8.36	−0.92	6.37	7.29	771.91	−417.34	0.36	–	–	–	–
391.4	9.04	−6.03	2.77	8.80	893.47	−411.50	0.51	1.29	1.28	534	6.88
288.5	9.70	−9.82	−0.12	9.69	942.55	−416.22	0.68	1.17	1.02	43.5	5.82
236.0	10.1	−12.21	−1.97	10.25	992.83	−421.29	0.84	1.11	0.95	36.3	5.54
Heating at 60 °C											
866.0	8.10	5.04	12.90	7.86	1138.86	−472.47	0.28	1.72	1.63	86.4	6.68
743.9	8.67	2.80	11.07	8.27	1016.58	−478.56	0.33	1.65	1.64	972	7.27
569.2	9.25	−0.92	7.96	8.89	993.98	−485.88	0.43	1.54	1.53	1370	7.16
386.3	9.86	−5.97	3.83	9.80	1073.50	−490.23	0.62	1.39	1.23	42.7	5.90
291.7	10.5	−9.41	1.33	10.73	1182.54	−500.89	0.81	1.28	1.03	21.9	5.06
235.5	10.8	−12.04	−0.54	11.49	1208.74	−499.86	0.99	1.19	0.96	22.3	4.91
Heating at 70 °C											
966.8	8.82	6.62	10.72	4.10	1255.64	−569.64	0.30	3.95	3.57	83.4	12.7
850.5	9.22	4.75	13.37	8.62	1182.30	−552.41	0.33	1.84	1.77	139	7.15
747.0	9.58	2.86	12.38	9.52	1174.38	−551.72	0.38	1.65	1.65	1633	7.03
573.1	10.2	−0.87	9.60	10.47	1053.56	−571.84	0.50	–	–	–	–
389.2	10.9	−5.94	5.56	11.51	1123.64	−567.60	0.72	1.37	1.28	66.1	5.89
290.7	11.3	−9.58	3.23	12.81	1201.03	−574.88	0.95	1.24	1.08	31.4	5.02
215.6	11.8	−12.99	1.63	14.63	1226.83	−582.59	1.26	1.09	0.91	21.6	4.35
Heating at 80 °C											
1076.8	9.28	8.11	17.82	9.71	1277.74	−591.05	0.28	1.77	1.74	223	6.63
946.3	10.0	6.43	15.95	9.52	1391.01	−637.26	0.34	1.94	1.77	47.7	6.45
855.1	9.87	4.71	14.90	10.19	1270.42	−628.52	0.38	–	–	–	–
744.5	10.6	2.92	13.68	10.76	1307.06	−642.74	0.44	1.71	1.64	103	6.49
569.2	10.9	−0.77	10.84	11.61	1202.59	−655.14	0.58	1.60	1.52	82.0	6.07
388.7	11.6	−5.46	7.77	13.23	1232.48	−647.87	0.79	1.38	1.13	18.7	4.57
288.1	11.9	−9.76	4.69	14.44	1138.66	−650.56	1.10	1.25	1.14	39.9	4.92
213.0	12.3	−13.42	2.27	15.68	1198.74	−623.28	1.41	1.09	1.02	53.2	4.81

Note the liquid surface temperature is -13.42C.

6.2 Second Comparative Analysis

Dewald's second analysis includes a number of average values, with the underlying data purportedly located within the data cited.[20]



The second comparison from this study was done using the complete E³ formula (free and bound water). Below is a list of the average temperature differences between the liquid and bulk vapor phase and the average listed raw vapor pressures (gpp) in each of the tests:

- Kasemi = 2.1K difference, 473 Pa (+/-13 Pa), 21 gpp
- Jafari = 2.6K difference, 596 Pa (+/-13 Pa), 26 gpp
- Fung, Ward, Duan = 25.6K difference, 438 Pa (+/-13 Pa), 19 gpp
- Badam = 66.5K difference, 582 Pa (+/-13 Pa), 25.5 gpp

Dewald references a table encompassing 31 data sets derived from similar experimental setups but originating from four distinct experimental sources, each of which runs experiments under different, dissimilar, ranges of conditions.

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[20] Dewald, p. 8.

It is important to recognize that averaging data for analytical purposes in this context is not statistically sound. Averaging would be appropriate when dealing with multiple data sets under identical or similar experimental conditions. However, averaging data from a range of experiments with considerable variation in test conditions is methodologically flawed.

For each of the four experimental sources, four variables are purportedly averaged. Dewald then employs these averages in the second comparative analysis, resulting in a total of 16 cited/calculated average values found at the bottom of page 9 in Dewald's paper.

Out of the 16 "average" values presented, only seven align with the actual averages of the data cited by Dewald. One appears to be a typographical error. An additional four appear to be erroneously derived from the incorrect column which were simulated rather than the actual experimental data, leaving four of the reported averages without substantiation based on the cited data table. These four unsubstantiated values appear to be carried over from the mass flux values from the four specific experiments in Comparison 1, rather than the appropriate average values from the table.

Again, Dewald lists unsubstantiated GPP values, with no reference condition listed. Dewald appears to utilize the temperature difference between T_B (bulk or boundary vapor temp) and the liquid surface temperature in place of "temperature discontinuity" values. No reason for this change in methodology is given. In comparison 1, Dewald appears to utilize T_B values for the calculation of the conditions that result in an E^3 score, but then corrects for the actual temperature discontinuity value. In comparison 2, Dewald again appears to utilize T_B values to calculate E^3, but then corrects for the difference between T_B value and that of the liquid. Both of these scenarios utilize an erroneous correction for the conditions at the evaporating interface, given that the E^3 formula does not have any inputs from surface temperature and is intended to evaluate "ambient" conditions rather than conditions inside the Knudsen layer.

On page 10, Dewald lists "Avg Tk(b) values." The first three values from the top are accurately averaged to a tenth of a degree. However, the final value listed for "Badam" is 249, while the actual value is 349, suggesting a typographical error.

The cited table includes both experimental data as well as data from computer simulations that were utilized to evaluate the phenomenon of temperature discontinuity. Dewald appears to intend to use the average of the experimental data, but arbitrarily utilizes the average values for the simulated liquid temperature rather than the average of the experimentally derived data, though not all four of these averages fully match either.

This rebuttal takes issue with the validity in comparing these experimental situations with that of the restoration industry. It also takes issue with the averaging of this type of data as well as applying any type of correction for surface phenomena or "per degree of temperature difference". The values presented for "average mass flux" do not correlate to the remainder of the data.
If one were to apply the correct average mass flux values in the table, utilizing Dewald's (contested) comparison framework (despite scientific and statistical concerns with the methodology and averaging strategies), the results are as follows:

note: **2.35** is the update correction value
- Kazemi baseline: 6.52 E^3 / **2.35** = 2.77 kg/m2-s (actual 2.77)
- Jafari: 8.46 E^3 / **2.35** = 3.6 (actual 2.35)
- Fung, Ward, Duan: 23.5 E^3 / **2.35** = 10 (actual 1.04)
- Badam: 31.6 E^3 / **2.35** = 13.44 (actual 7.28)

Comparing these to the Kazemi baseline per Dewald's contended strategy, the error rates are:
- Jafari: E^3 prediction is 53% high
- Fung, Ward, Duan: E^3 prediction is 961% high
- Badam: E^3 prediction is 84% high

This results in an average error rate of 366%.

Note it is inappropriate to include the reference condition and associated "0% error" when presenting data such as this.

6.2.1 Supporting Information

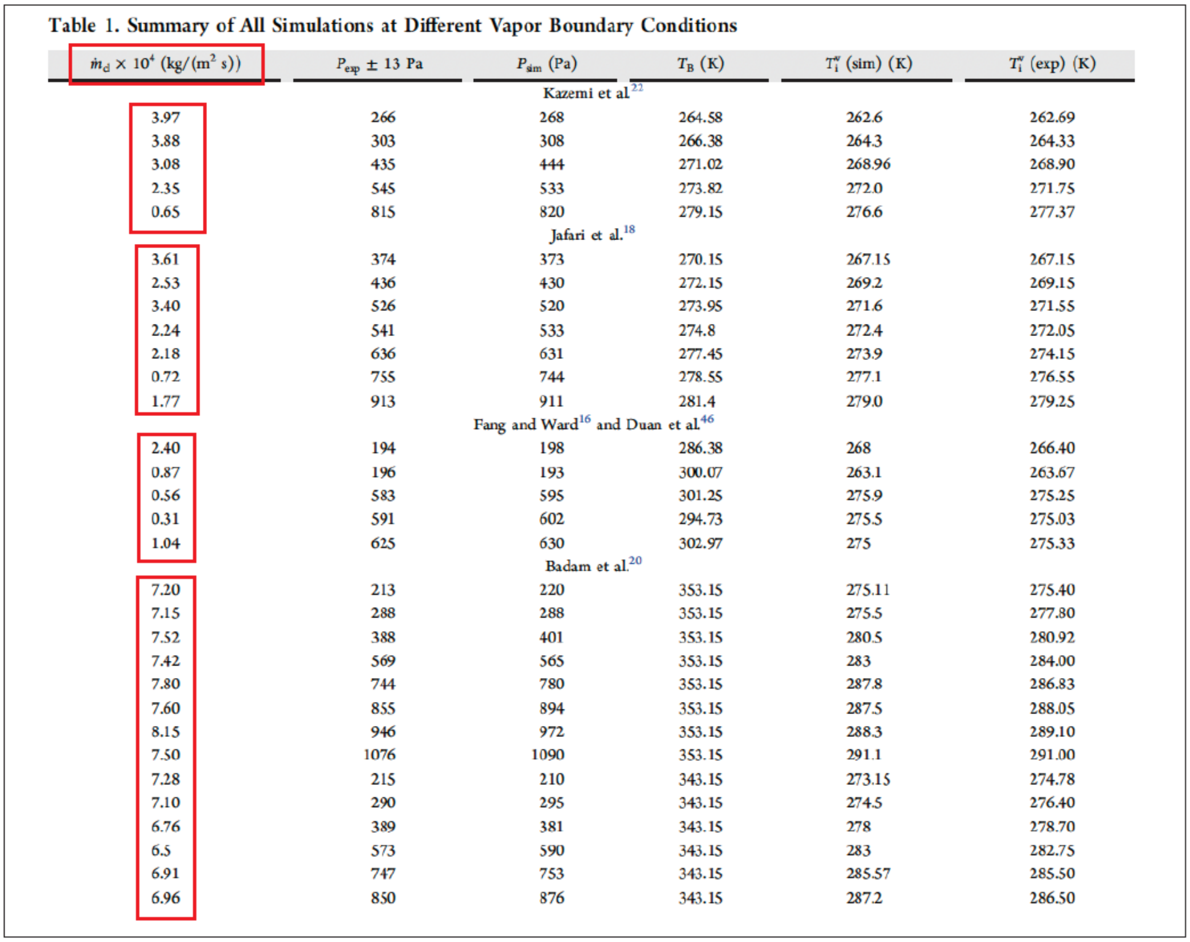

Table 1. Summary of All Simulations at Different Vapor Boundary Conditions

$\dot{m}_d \times 10^4$ (kg/(m^2 s))	P_{exp} ± 13 Pa	P_{sim} (Pa)	T_B (K)	T_i^v (sim) (K)	T_i^v (exp) (K)
Kazemi et al[22]					
3.97	266	268	264.58	262.6	262.69
3.88	303	308	266.38	264.3	264.33
3.08	435	444	271.02	268.96	268.90
2.35	545	533	273.82	272.0	271.75
0.65	815	820	279.15	276.6	277.37
Jafari et al.[18]					
3.61	374	373	270.15	267.15	267.15
2.53	436	430	272.15	269.2	269.15
3.40	526	520	273.95	271.6	271.55
2.24	541	533	274.8	272.4	272.05
2.18	636	631	277.45	273.9	274.15
0.72	755	744	278.55	277.1	276.55
1.77	913	911	281.4	279.0	279.25
Fang and Ward[16] and Duan et al[46]					
2.40	194	198	286.38	268	266.40
0.87	196	193	300.07	263.1	263.67
0.56	583	595	301.25	275.9	275.25
0.31	591	602	294.73	275.5	275.03
1.04	625	630	302.97	275	275.33
Badam et al[20]					
7.20	213	220	353.15	275.11	275.40
7.15	288	288	353.15	275.5	277.80
7.52	388	401	353.15	280.5	280.92
7.42	569	565	353.15	283	284.00
7.80	744	780	353.15	287.8	286.83
7.60	855	894	353.15	287.5	288.05
8.15	946	972	353.15	288.3	289.10
7.50	1076	1090	353.15	291.1	291.00
7.28	215	210	343.15	273.15	274.78
7.10	290	295	343.15	274.5	276.40
6.76	389	381	343.15	278	278.70
6.5	573	590	343.15	283	282.75
6.91	747	753	343.15	285.57	285.50
6.96	850	876	343.15	287.2	286.50

“Kazemi" Data	mass flux	P_{exp}	T_B	T_i (exp)	Temp Diff (T_B - T_i (exp))	T_i (sim)	Temp. Diff. (T_i exp – T_l Sim)
	3.97	266	264.58	262.69		262.6	
	3.88	303	266.38	264.33		264.3	
	3.08	435	271.02	268.9		268.96	
	2.25	545	273.82	271.75		272	
	0.65	815	279.15	277.37		276.6	
Real Average	2.766	472.8	270.99	269.008	1.982	269.9	2.1
Dewald’s claimed average p.8 Comparison 1	2.41	435	271		0.24		
Dewald’s claimed average p.9 Comparison 2	2.41	473	271		2.1		

For this and following similar tables: Green shading indicates correct values, red shading indicates incorrect values, and orange indicates values similar to the correct values but outside of anticipated rounding.

It appears Dewald utilized the average temperature difference between the simulated liquid temperature rather than the experimentally measured liquid temperature.

Dewald claims the average evaporation, or mass flux rate, for the Kazemi data, is 2.41. The actual average of the data cited is 2.766. No explanation is given for this discrepancy. This discrepancy impacts the accuracy claims made by Dewald.

"Jafari" Data	mass flux	P_{exp}	T_B	T_i (exp)	Temp Diff (T_B - T_i (exp))	T_i (sim	Temp. Diff. (T_i exp – T_ι Sim)
	3.61	374	270.15	267.15		267.15	
	2.53	436	272.15	269.15		269.2	
	3.4	526	273.95	271.55		271.6	
	2.24	541	274.8	272.05		272.4	
	2.18	636	277.45	274.15		273.9	
	0.72	755	278.55	276.55		277.1	
	1.77	913	281.4	279.25		279.0	
Real average	2.35	597.3	275.49	272.84	2.65	272.9	2.6
Dewald's claimed average p.8 Comparison 1	3.1	446	274		0.4		
Dewald's claimed average p.9 Comparison 2	3.1	596	275.5		2.6		

It appears Dewald utilized the average temperature difference between the simulated liquid temperature rather than the experimentally measured liquid temperature.

Dewald claims the average evaporation, or mass flux rate, for the Jafari data is 3.1. The actual average of the data cited is 2.35. No explanation is given for this discrepancy. This discrepancy impacts the accuracy claims made by Dewald.

"Duan" Data	mass flux	P_{exp}	T_B	T_i (exp)	Temp Diff (T_B - T_i (exp))	T_i (sim	Temp. Diff. (T_i exp – T_l Sim)
	2.4	194	286.38	266.4		268	
	0.87	196	300.07	263.67		263.1	
	0.56	583	301.25	275.25		275.9	
	0.31	591	294.73	275.03		275.5	
	1.04	625	302.97	275.33		275	
Real Average	1.036	437.8	297.08	271.136	25.944	271.5	25.6
Dewald's claimed average p.8 Comparison 1	8.65	176	297		5.3		
Dewald's claimed average p.9 Comparison 2	8.65	438	297.1		25.6		

It appears Dewald utilized the average temperature difference between the simulated liquid temperature rather than the experimentally measured liquid temperature.

Dewald claims the average evaporation, or mass flux rate, for the Duan data is 8.65. The actual average of the data cited is 1.036. No explanation is given for this discrepancy. This discrepancy impacts the accuracy claims made by Dewald.

"Badam" Data	mass flux	P_{exp}	T_B	T_i (exp)	Temp Diff (T_B - T_i (exp))	T_i (sim	Temp. Diff. (T_i exp – T_l Sim)
	7.2	213	353.15	275.4		275.11	
	7.15	288	353.15	277.8		275.5	
	7.52	388	353.15	280.92		280.5	
	7.42	569	353.15	284		283	
	7.8	744	353.15	286.83		287.8	
	7.6	855	353.15	288.05		287.5	
	8.15	946	353.15	289.1		288.3	
	7.5	1076	353.15	291		291.1	
	7.28	215	343.15	274.78		273.15	
	7.1	290	343.15	276.4		274.5	
	6.76	389	343.15	278.7		278	
	6.5	573	343.15	282.75		283	

	6.91	747	343.15	285.5		285.57	
	6.96	850	343.15	286.5		287.2	
average	7.275	581.642	348.9	282.7	66.2	282.2	66.7
Dewald’s claimed average p.8 Comparison 1	12.3	213	349		15.6		
Dewald’s claimed average p.9 Comparison 2	12.3	582	249*		66.5		

It appears Dewald utilized the average temperature difference between the simulated liquid temperature rather than the experimentally measured liquid temperature. In this instance the value utilized in Comparison 2 does not fully match the simulated data.

Dewald asserts that the average evaporation or mass flux rate for the Badam data is 12.3. However, the actual average of the cited data is 7.275. No explanation is given for this discrepancy. This discrepancy impacts the accuracy claims made by Dewald.

7. Conclusion

In concluding the rebuttal to “Enthalpy Evaporation Evaluation — A Case for the E^3 Drying Metric," the proportionality claim that an E^3 score of 200 “*would dry or evaporate water from all materials twice as fast as an* E^3 score of 100” is faulty. With the implied presumption that material temperatures will equalize with ambient temperatures, Dewald’s claim cannot be validated against established scientific principles related to drying rates, evaporation processes, or the known forces which influence how water molecules move through hygroscopic materials and assemblies. Beyond Dewald’s primary claim, the attempts to validate the metric against third-party data are not compelling, are questionably derived, and contain a number of substantial errors and omissions. No known first-party data or validation has been presented.

E^3 fails to consistently correlate and evaluate drying forces and their direction acting upon hygroscopic materials across varied ambient conditions. E^3’s fundamental flaws and unreliability across the diverse conditions encountered in water damage restoration result in diminished value when used secondarily for target values and drying system comparisons. The E^3 formula appears to give little consideration to external forces that can influence the rate of evaporation or lack thereof, of water within diverse materials.

It is proposed that further research and collaborative industry efforts are essential to refine and validate any new methodology, ensuring it is both scientifically sound and practically applicable. Rigorous field testing and proper peer review can aid with aligning new methodologies to the diverse realities faced by the restoration industry.

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