BUILDING ENVELOPE TECHNOLOGY SYMPOSIUM

USING HUMIDITY/TEMPERATURE LOGGERS FOR MOISTURE INVESTIGATIONS: CASE STUDIES

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ABSTRACT

This presentation will introduce a minimum level of moisture science and then shows how the moisture (vapor) content of the ambient air in attics, rooms, and wall cavities is easily measured. Brief case studies will be used to demonstrate that extended series of moisture (vapor) content measurements can, in certain cases, be as informative to builders, roofers, and forensic professionals as comparative measurements of the moisture (water) content of roof decking, wood studs, or exterior sheathing. The simple goal of the presentation is to introduce nonexperts to practical applications of a useful investigative tool.

SPEAKER

LONNIE HAUGHTON — RICHARD AVELAR & ASSOCIATES

Lonnie Haughton uses forensic expertise and a wide range of investigative tools – moisture meters, water-finding test paper, *in-situ* sensors, calcium chloride vapor domes, hygrometers, psychrometric tables, and WUFI software – to solve difficult leakage and condensation puzzles in California and Nevada, including claims of roof "leakage" that only occur during hot, sunny days. He has led a variety of training sessions for contractors and forensic professionals that describe practical examples where various types of humidity meters were used to resolve claims of building envelope defects. Haughton is an ICC-certified Master Code Professional, a building inspector and building plans examiner, an EDI-certified EIFS Third-Party Inspector, and a California-licensed general contractor.

Using Humidity/Temperature Loggers for Moisture Investigations: Case Studies

ABSTRACT

This paper demonstrates that portable humidity/temperature loggers are useful tools for interior moisture investigations. The author:

1. Strives to explain relative humidity in easy-to-understand terms;
2. Introduces fundamental aspects of "psychrometrics" (the science and measurement of air-water interaction), including the "humidity ratio" (the water vapor content of ambient air);
3. Establishes that calculation of a space's humidity ratio is a simple matter if the space's ambient temperature, relative humidity, and altitude are known;
4. Presents short case studies that provide examples of valuable information that can be gained from evaluations of multiweek series of humidity ratio calculations from data collected by portable humidity/temperature loggers; and
5. Summarizes introductory guidelines for using multiple humidity/temperature loggers to solve complex cases of problematic building performance.

RELATIVE HUMIDITY

The concept of "relative humidity" can be confusing.[1] Arguably, a majority of contractors and building envelope professionals misunderstand the term. In some cases, this confusion leads to failures to recognize problematic levels of interior moisture or, alternatively, undue concerns of excess humidity when none exists.

Many construction professionals mistakenly believe that relative humidity (RH) is equivalent to moisture content. For example, they might assume that an apartment that registers 66% RH is always "wetter" (i.e., contains a higher ratio of ambient water vapor molecules) than a nearby apartment that registers 33% RH. When they are informed that the opposite may be true – the ambient space with 33% RH may be wetter than the ambient space with 66% RH – some individuals may conclude that RH simply is too complex for an average person to comprehend. The first goal of this paper is to explain in easy-to-understand terms what RH is and is not.

How could an apartment that registers 33% RH be wetter than a nearby apartment that registers 66% RH? Because:

1. The maximum possible amount of ambient water vapor in any enclosed space is a direct function of the ambient temperature of this space; the warmer an enclosed space, the more ambient water vapor molecules that can be maintained within it.[2]
2. Relative humidity of 100% is defined as the point at which no additional amount of ambient water vapor molecules can be maintained within an enclosed space. Lower relative humidity readings, such as 33% RH or 66% RH, simply tell us the current percentage of ambient vapor molecules within a particular space compared to the maximum possible at that space's current temperature.[3]
3. In short, a 33% RH reading in a warm space may represent a larger quantity of water vapor than a 66% RH reading in an identical unheated space.
4. In other words, direct comparisons of differing RH readings are not sufficient, in and of themselves, to inform us which enclosed space contains the highest quantity or percentage of ambient water vapor molecules.[4]

As an analogy, relative humidity readings can be compared to the fuel gauges in our vehicles. Some vehicles have large fuel tanks, while other tanks are much smaller. Depending upon the magnitude of their differing sizes, a tank that is one-third full may contain more fuel than a tank that is two-thirds full. Consider, for example, a Ford F-150 Super Crew pickup with a fuel capacity of 36 gallons and a Ford Focus coupe with a fuel capacity of 13½ gallons. When the coupe's fuel gauge indicates that the tank is 66% full, the tank contains only 9 gallons. When the F-150's gauge indicates that the tank is 33% full, the tank still contains more fuel than the coupe. If both tanks are equally full (whether 10%, 33%, 66% or 100%), the F-150 tank contains about 244% more fuel than the coupe's tank.

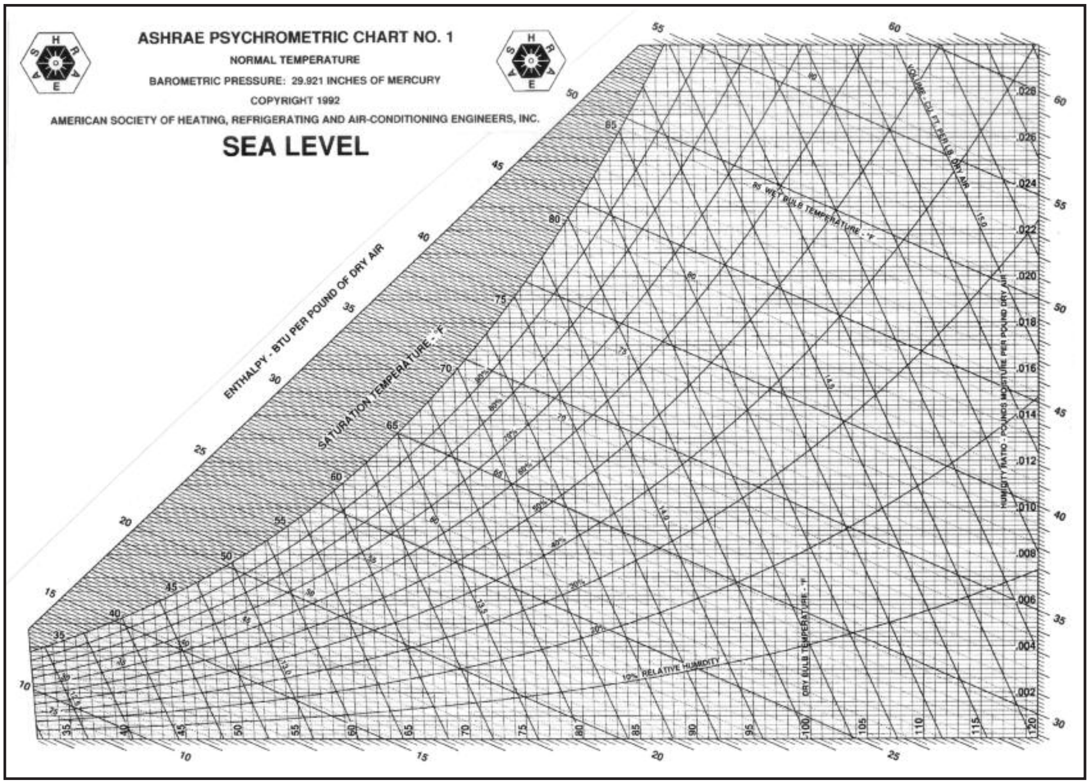
Similarly, let's consider a heated apartment on a cool day in Seattle with an ambient indoor temperature of 74°F, and a nearby, unheated apartment with an ambient temperature of 49°F. Moisture science informs us that if these identically configured apartments have the same RH, then the heated apartment (the Ford F-150) contains about 244% more ambient water vapor than the unheated apartment (the Ford Focus).

Continuing this tank analogy, while it is clear that our vehicle fuel gauges provide highly useful guidance to drivers as we calculate when next to refuel, unless we also know the specific capacity of each tank, these gauges are not sufficient to inform us of the actual amount of remaining fuel. In a similar manner, while RH measurements can be informative to certain construction, engineering, and mold professionals, such readings are not sufficient, in and of themselves, to inform us of the actual moisture (vapor) content at the tested areas. Instead, as demonstrated below, to calculate ambient moisture content, we also need to know the test space's temperature and altitude.

PSYCHROMETRICS 101

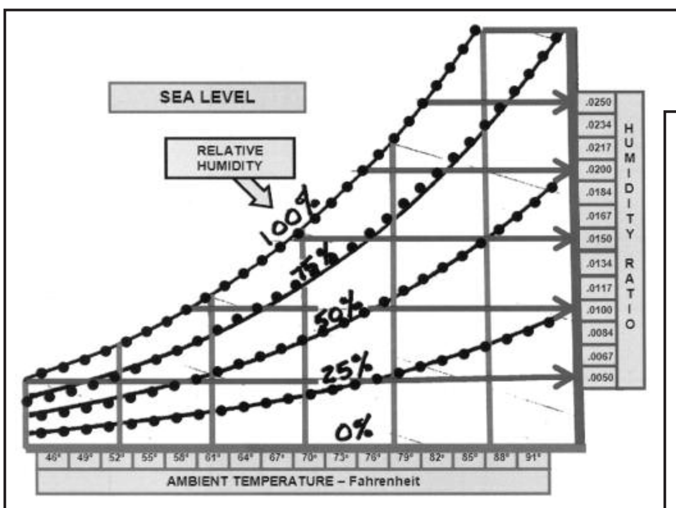
Psychrometrics is the science and measurement of air-water interaction.[5] The complex essence of the science is summarized in the standard ASHRAE[6] psychrometric chart seen in *Figure 1*; however, many highly skilled construction professionals would argue that only an engineer could love this seemingly Byzantine graph. Note: Donald Gatley's *Understanding Psychrometrics, Second Edition*, published by ASHRAE in 2005, provides an excellent introduction to the science and history of psychrometrics and psychrometric charts and is referenced often within this paper.

An encyclopedic wealth of information is



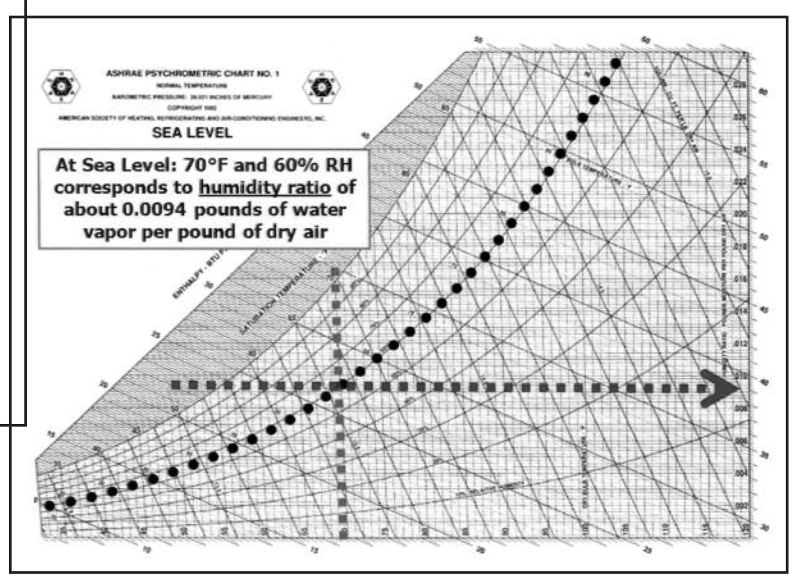
compressed into these ASHRAE charts; however, for the purposes of this paper, the most important streams of psychrometric data are those identified in *Figure 2*:

- Relative humidity (see the upward-curving lines)
- Dry bulb temperature (see the almost-vertical lines) is the ambient temperature, as measured by a common thermometer.
- Humidity ratio (see the horizontal lines) is the actual numerical ratio of the mass of ambient water vapor to the mass of dry ambient air.[7]



The humidity ratio (measured in pounds of water vapor per pound of dry air) represents the actual moisture content (MC) ratio of the ambient air in the same manner that a common pin-style moisture meter measures the MC of wet wood by calculating the ratio of the weight of the water in the wood as a percentage of the weight of the dry wood substance. In the standard psychrometric chart, the humidity ratio is found by projecting a horizontal line from the intersection of the near-vertical ambient temperature line and the upward-curving RH line.

For example, we see in *Figure 3* that measurements of 70° F and 60% RH taken at an apartment in San Francisco correspond to an ambient moisture content of about 0.0094 pounds of water vapor per pound of dry air. In other words, these two measurements demonstrate that water vapor comprises about 0.94 percent of the ambient air at this San Francisco apartment. It is important to note that there are numerous intersections of RH and ambient temperature that also correspond to 0.0094 pounds of water vapor per pound of dry air: (e.g., 57° F | 96% RH and 75° F | 52% RH and 85° F | 37% RH). Again, RH measurements alone are not sufficient to inform us of the actual percentage of ambient mois-



ture at the test area.

Figure 3 also demonstrates that using a traditional ASHRAE chart to make humidity ratio calculations can be a tediously uncertain process, which explains the burgeoning popularity of psychrometric software.[8]

For example, the field inspection tables in *Figure 4* (base altitude: sea level)[9] and *Figure 5* (base altitude: 1,000 feet) were generated with readily available software.

- Note 1: A variable in humidity ratio calculations is barometric pressure, which commonly is approximated by inputting the altitude of the tested space;[10] however, for the rough field analyses addressed by *Figures 4* and *5*, such altitude effects reasonably can be ignored.[11] Similar tables easily can be produced for high-altitude projects.
- Note 2: Field tables in *Figures 4* and *5* should be used only for the approximate building performance evaluations described within this paper. The provided humidity ratio data (pounds of water vapor per pound of dry air) are rounded to the nearest one-thousandth (e.g., 0.009443 is rounded down to 0.009 and 0.009522 is rounded up to 0.010.) These rounded values should not be used for psychrometric analyses that require a higher degree of accuracy.

TEMPERATURE/RH LOGGERS AND PSYCHROMETRIC SOFTWARE

RH measurements throughout an enclosed space can vary widely in direct response to temperature fluctuations. In contrast, the second law of thermodynamics[12] dictates that the water vapor molecules contained within this space always are striving to remain equally distributed.[13] For example, a sudden influx of additional water vapor (e.g., from a teakettle) quickly disperses equally throughout the space. Barring a moisture event (such as unventilated cooking or showering) or a dehumidification event (e.g., operation of an exhaust fan), significant increases or decreases in the actual moisture vapor content of the enclosed space tend to occur relatively slowly. The intent of this paper is to demonstrate the use of temperature/RH loggers to monitor the rise and fall of these humidity ratio trends over an extended period (e.g., 20 to 60 days) in order to then evaluate when and why these changes occurred.

Sea Level	Ambient Temperature (F°)										
Pounds of Moisture per Pound of Dry Air	40°F	45°F	50°F	55°F	60°F	65°F	70°F	75°F	80°F	85°F	90°F
.001	10% RH	09% RH	07% RH	06% RH	05% RH	04% RH	04% RH	03% RH	03% RH	02% RH	02% RH
.002	30% RH	24% RH	20% RH	17% RH	14% RH	12% RH	10% RH	09% RH	07% RH	06% RH	06% RH
.003	49% RH	41% RH	34% RH	28% RH	23% RH	20% RH	17% RH	14% RH	12% RH	10% RH	09% RH
.004	68% RH	57% RH	47% RH	39% RH	33% RH	27% RH	23% RH	23% RH	17% RH	14% RH	12% RH
.005	87% RH	74% RH	60% RH	50% RH	42% RH	35% RH	30% RH	26% RH	21% RH	18% RH	16% RH
.006	xx	88% RH	73% RH	61% RH	51% RH	43% RH	36% RH	30% RH	26% RH	22% RH	19% RH
.007	xx	xx	86% RH	71% RH	60% RH	50% RH	42% RH	36% RH	30% RH	26% RH	22% RH
.008	xx	xx	99% RH	82% RH	69% RH	58% RH	49% RH	41% RH	35% RH	30% RH	26% RH
.009	xx	xx	xx	93% RH	78% RH	65% RH	55% RH	47% RH	40% RH	34% RH	29% RH
.010	xx	xx	xx	xx	87% RH	73% RH	61% RH	52% RH	44% RH	38% RH	32% RH
.011	xx	xx	xx	xx	96% RH	80% RH	68% RH	57% RH	49% RH	41% RH	35% RH
.012	xx	xx	xx	xx	xx	88% RH	74% RH	63% RH	53% RH	45% RH	39% RH
.013	xx	xx	xx	xx	xx	95% RH	80% RH	68% RH	58% RH	49% RH	43% RH
.014	xx	xx	xx	xx	xx	xx	86% RH	73% RH	62% RH	53% RH	45% RH
.015	xx	xx	xx	xx	xx	xx	93% RH	78% RH	66% RH	57% RH	48% RH
.016	At 100% RH (i.e., at Dewpoint Temperature)						99% RH	84% RH	71% RH	60% RH	52% RH
.017	Excess Water Vapor Condenses into Liquid						xx	89% RH	75% RH	64% RH	55% RH
.018	xx	xx	xx	xx	xx	xx	xx	94% RH	80% RH	68% RH	58% RH

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1000 Feet	Ambient Temperature (F°)										
Pounds of Moisture per Pound of Dry Air	40°F	45°F	50°F	55°F	60°F	65°F	70°F	75°F	80°F	85°F	90°F
.001	10% RH	08% RH	07% RH	06% RH	05% RH	04% RH	04% RH	03% RH	03% RH	02% RH	02% RH
.002	30% RH	24% RH	20% RH	16% RH	14% RH	12% RH	10% RH	08% RH	07% RH	06% RH	05% RH
.003	47% RH	39% RH	32% RH	27% RH	23% RH	19% RH	16% RH	14% RH	12% RH	10% RH	09% RH
.004	66% RH	54% RH	45% RH	38% RH	31% RH	26% RH	22% RH	19% RH	16% RH	14% RH	12% RH
.005	84% RH	70% RH	58% RH	48% RH	40% RH	34% RH	29% RH	24% RH	21% RH	18% RH	15% RH
.006	xx	85% RH	70% RH	59% RH	49% RH	41% RH	35% RH	29% RH	25% RH	21% RH	18% RH
.007	xx	xx	83% RH	69% RH	58% RH	48% RH	41% RH	35% RH	29% RH	25% RH	21% RH
.008	xx	xx	95% RH	79% RH	66% RH	56% RH	47% RH	40% RH	34% RH	29% RH	25% RH
.009	xx	xx	xx	90% RH	75% RH	63% RH	53% RH	45% RH	38% RH	34% RH	28% RH
.010	xx	xx	xx	xx	84% RH	70% RH	59% RH	50% RH	43% RH	36% RH	31% RH
.011	xx	xx	xx	xx	92% RH	77% RH	65% RH	55% RH	47% RH	40% RH	34% RH
.012	xx	xx	xx	xx	xx	85% RH	71% RH	60% RH	51% RH	44% RH	38% RH
.013	xx	xx	xx	xx	xx	92% RH	77% RH	65% RH	56% RH	47% RH	40% RH
.014	xx	xx	xx	xx	xx	99% RH	83% RH	71% RH	60% RH	51% RH	44% RH
.015	xx	xx	xx	xx	xx	xx	89% RH	76% RH	64% RH	55% RH	47% RH
.016	At 100% RH (i.e., at Dewpoint Temperature)						95% RH	81% RH	68% RH	58% RH	50% RH
.017	Excess Water Vapor Condenses into Liquid						xx	86% RH	73% RH	62% RH	53% RH
.018	xx	xx	xx	xx	xx	xx	xx	91% RH	77% RH	66% RH	56% RH

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For example, let's assume that during brief initial surveys in eight units at a water-damaged apartment building, the humidity ratios measured in seven of the inspected apartments range from 0.006 to 0.008 pounds of ambient water vapor per pound of dry air,[14] but the humidity ratio measured at one unit is 0.012 pounds of ambient moisture per pound of dry air. In other words, the ambient moisture content of one of the apartments is 50% to 100% greater than other nearby units. Such discrepancies simply may be a transient result of differing lifestyles; however, as demonstrated later in this paper, it also may indicate a building performance failure.

In either case, the presence or absence of large variances in long-term average humidity ratio readings at similarly occupied spaces can help guide the initial phases of forensic investigation and destructive testing at a project. The first step toward gaining this information is to deploy portable temperature/RH loggers (see *Photo 1*) to collect extended series of ambient temperature and relative humidity measurements.[15]

- **Tip:** For most testing of enclosed spaces, whether inside a room or within a wall cavity, the datalogger(s) should not be positioned immediately adjacent to potential sources of moisture production or intrusion. As noted above, water vapor (e.g., from a teakettle) soon disperses equally throughout an enclosed space. To best understand the overall impact of the teakettle's vapor production on the apartment's ambient air, the data series collected

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#	Date and Time	Temp. (°F)	Humidity (%RH)		Humidity Ratio
13765	3/25/2009 12:00	69.98	41.00	41.0%	0.0064
13766	3/25/2009 12:05	69.98	41.00	41.0%	0.0064
13767	3/25/2009 12:10	69.98	41.00	41.0%	0.0064
13768	3/25/2009 12:15	69.98	41.00	41.0%	0.0064
13769	3/25/2009 12:20	70.16	41.00	41.0%	0.0064
13770	3/25/2009 12:25	70.16	41.00	41.0%	0.0064
13771	3/25/2009 12:30	70.16	41.00	41.0%	0.0064
13772	3/25/2009 12:35	70.16	40.50	40.5%	0.0063
13773	3/25/2009 12:40	70.16	41.00	41.0%	0.0064
13774	3/25/2009 12:45	70.16	40.50	40.5%	0.0063
13775	3/25/2009 12:50	70.16	41.00	41.0%	0.0064
13776	3/25/2009 12:55	70.16	41.00	41.0%	0.0064
13777	3/25/2009 13:00	70.16	40.50	40.5%	0.0063
13778	3/25/2009 13:05	70.16	41.00	41.0%	0.0064
13779	3/25/2009 13:10	70.16	41.00	41.0%	0.0064
13780	3/25/2009 13:15	70.16	41.00	41.0%	0.0064
13781	3/25/2009 13:20	70.34	41.00	41.0%	0.0064
13782	3/25/2009 13:25	70.16	41.00	41.0%	0.0064
13783	3/25/2009 13:30	70.34	41.00	41.0%	0.0064
13784	3/25/2009 13:35	70.34	41.00	41.0%	0.0064
13785	3/25/2009 13:40	70.34	41.00	41.0%	0.0064
13786	3/25/2009 13:45	70.34	41.00	41.0%	0.0064
13787	3/25/2009 13:50	70.34	41.00	41.0%	0.0064
13788	3/25/2009 13:55	70.52	41.00	41.0%	0.0065
13789	3/25/2009 14:00	70.52	41.00	41.0%	0.0065
13790	3/25/2009 14:05	70.52	41.00	41.0%	0.0065
13791	3/25/2009 14:10	70.52	41.00	41.0%	0.0065
13792	3/25/2009 14:15	70.52	41.00	41.0%	0.0065
13793	3/25/2009 14:20	70.52	41.00	41.0%	0.0065
13794	3/25/2009 14:25	70.52	41.00	41.0%	0.0065
13795	3/25/2009 14:30	70.52	41.00	41.0%	0.0065
13796	3/25/2009 14:35	70.52	41.00	41.0%	0.0065
13797	3/25/2009 14:40	70.52	41.00	41.0%	0.0065
13798	3/25/2009 14:45	70.52	41.00	41.0%	0.0065
13799	3/25/2009 14:50	70.52	41.00	41.0%	0.0065
13800	3/25/2009 14:55	70.52	41.00	41.0%	0.0065
13801	3/25/2009 15:00	70.52	41.00	41.0%	0.0065
13802	3/25/2009 15:05	70.52	41.00	41.0%	0.0065
13803	3/25/2009 15:10	70.52	41.00	41.0%	0.0065

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from a sensor located 10 feet away will be more readily useful than the more-varied data taken at the teakettle's spout.

After the temperature/RH logger(s) has (have) been retrieved, their digital data are transferred to a computer for storage, processing, and review via proprietary software and Microsoft's ubiquitous Excel® spreadsheet program. Investigators who are reasonably skilled with Excel have numerous options for analytical, statistical, and comparative evaluations of data streams from one or many dataloggers.

Firstly, each line of the duplex raw data (temperature and RH) can be processed with psychrometric software that incorporates the project's altitude to calculate the current humidity ratio at the test location.[16] *Figure 6* presents a typical matrix by the author with humidity ratios that have been calculated from duplex temperature and RH readings recorded every five minutes.

The next step is to analyze a series of multiple hundreds or thousands of such humidity ratio calculations for evidence (or the lack of evidence) of unexpected or unusual moisture fluctuations and their potential sources. An experienced user of Excel® easily can determine the average, maximum, and minimum humidity ratios for the extended test period and for key blocks of time; e.g., during rainy weather or during the occupant's regular lifestyle activities and/or any other interesting variable.

CASE STUDIES

The following case studies briefly demonstrate how extended series of humidity ratio calculations were analyzed to evaluate occupants' complaints of excessive condensation at aluminum-framed windows at three residential units in the San Francisco Bay metropolitan area. These case studies inform us that even though the initial complaints were similar, the humidity ratio analyses revealed strikingly different explanations for the condensation problems.

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CASE STUDY 1

- **Location:** Top-floor (third-story), one-bedroom condominium unit (see *Photo 2*) in Berkeley, CA, with a low-slope roofing system, a typical stucco-clad wood-framed building envelope, and aluminum-framed fenestrations.
- **Status:** As part of ongoing construction-defects litigation, the deficient roof covering system and failed stucco cladding already have been removed and replaced without replacement of the original windows. In accordance with minimum California code requirements, the only forms of mechanical ventilation within the dwelling are a bathroom fan and an exhaust fan at the kitchen range hood. The bathroom exhaust fan is used only when the bachelor homeowner takes his morning shower, and the kitchen range hood fan is used only occasionally.
- **Issue:** Even after replacement of the problematic stucco and roof covering system, the homeowner has continued to complain of moisture condensation at the interior glazing of the aluminum-framed windows, particularly at bedroom windows adjacent to the bathroom and at windows near the kitchen. Both the homeowners' association (HOA) and the homeowner are unwilling to accept the contractors' stucco and roofing repairs without independent assurance that the current condensation problems likely do not result from weather-related moisture intrusion due to unknown installation deficiencies.
- **Research:** Review of published technical specifications confirms that the aluminum-framed windows were manufactured with a relatively poor condensation resistance factor (CRF). During an interview, the homeowner reports observing the problematic condensation only during morning hours (i.e., during the period where he showers and then prepares breakfast prior to leaving for work).
- **Analysis:** A temperature/RH datalogger positioned within the unit during a six-week period collected more than 12,000 duplex measurements (taken at five-minute intervals). About 2,000 of these duplex readings were taken during a 1-week rainy period when the homeowner was away on vacation. In *Figure 7*, we see that during this particular 1-week period when the unit was unoccupied, the average (mean) humidity ratio of the dwelling was 0.0065 pounds of water vapor per pound of dry air. In contrast, in *Figure 8* we see that the average humidity ratio for the total five-week period (before and after the one-week vacation) when the unit was intermittently occupied was 0.0084 pounds of water vapor per pound of dry air. In short, even during mostly sunny weather, the average ambient moisture content of the occupied interior space was 30% greater than the fully unoccupied unit during a week of storms.
- **Finding:** Our clients (the homeowner and the HOA) were advised that this nonintrusive testing supported the stucco/roofing contractors' position that the moderate interior condensation likely resulted from lifestyle activities, insufficient mechanical ventilation, and/or low-grade windows, not hidden failures within the reconstructed building envelope.

MadgeTech Datalogger: N02161

Maximum Value of Humidity Ratio: 0.0076
Minimum Value of Humidity Ratio: 0.0059
Average (Mean) Value of Humidity Ratio: 0.0065
Average (Mean) Value of Temperature: 66.0330

#	Date and Time	Temp. (°F)	Humidity (%RH)		Humidity Ratio
2073	2/12/2009 21:40	66.74	48.50	48.5%	0.0067
2074	2/12/2009 21:45	66.74	48.50	48.5%	0.0067
2075	2/12/2009 21:50	67.10	48.50	48.5%	0.0068
2076	2/12/2009 21:55	67.28	48.50	48.5%	0.0069
2077	2/12/2009 22:00	67.64	48.50	48.5%	0.0070
2078	2/12/2009 22:05	68.00	48.50	48.5%	0.0070
2079	2/12/2009 22:10	68.36	48.00	48.0%	0.0071
2080	2/12/2009 22:15	68.54	47.50	47.5%	0.0070
2081	2/12/2009 22:20	68.90	47.50	47.5%	0.0071
2082	2/12/2009 22:25	69.08	47.00	47.0%	0.0071
2083	2/12/2009 22:30	69.44	47.00	47.0%	0.0072
2084	2/12/2009 22:35	69.62	47.00	47.0%	0.0072
2085	2/12/2009 22:40	69.80	47.00	47.0%	0.0073
2086	2/12/2009 22:45	69.98	47.00	47.0%	0.0073
2087	2/12/2009 22:50	70.16	46.50	46.5%	0.0073
2088	2/12/2009 22:55	70.34	46.50	46.5%	0.0073
2089	2/12/2009 23:00	70.52	46.50	46.5%	0.0074
2090	2/12/2009 23:05	70.70	46.50	46.5%	0.0074
2091	2/12/2009 23:10	70.88	46.00	46.0%	0.0074
2092	2/12/2009 23:15	71.24	46.00	46.0%	0.0075
2093	2/12/2009 23:20	71.24	46.00	46.0%	0.0075
2094	2/12/2009 23:25	71.60	46.00	46.0%	0.0076
2095	2/12/2009 23:30	71.60	45.00	45.0%	0.0074
2096	2/12/2009 23:35	71.42	45.00	45.0%	0.0073
2097	2/12/2009 23:40	71.24	45.00	45.0%	0.0073
2098	2/12/2009 23:45	71.24	45.00	45.0%	0.0073
2099	2/12/2009 23:50	71.06	45.00	45.0%	0.0073
2100	2/12/2009 23:55	71.06	45.00	45.0%	0.0073
2101	2/13/2009 0:00	70.88	45.00	45.0%	0.0072
2102	2/13/2009 0:05	70.88	45.00	45.0%	0.0072
2103	2/13/2009 0:10	70.70	45.00	45.0%	0.0072
2104	2/13/2009 0:15	70.70	45.00	45.0%	0.0072
2105	2/13/2009 0:20	70.70	46.00	46.0%	0.0073
2106	2/13/2009 0:25	70.52	46.00	46.0%	0.0073
2107	2/13/2009 0:30	70.34	45.50	45.5%	0.0072
2108	2/13/2009 0:35	70.34	45.50	45.5%	0.0072
2109	2/13/2009 0:40	70.16	45.50	45.5%	0.0071
2110	2/13/2009 0:45	69.98	45.50	45.5%	0.0071
2111	2/13/2009 0:50	69.98	45.50	45.5%	0.0071
2112	2/13/2009 0:55	69.80	45.50	45.5%	0.0070
2113	2/13/2009 1:00	69.80	45.50	45.5%	0.0070
2114	2/13/2009 1:05	69.80	46.50	46.5%	0.0072
2115	2/13/2009 1:10	69.62	46.50	46.5%	0.0071
2116	2/13/2009 1:15	69.62	46.50	46.5%	0.0071

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MadgeTech Datalogger: N02161

Maximum Value of Humidity Ratio: 0.0108
Minimum Value of Humidity Ratio: 0.0071
Average (Mean) Value of Humidity Ratio: 0.0084
Average (Mean) Value of Temperature: 71.6350

#	Date and Time	Temp. (°F)	Humidity (%RH)		Humidity Ratio
5293	2/24/2009 2:00	73.58	50.50	50.5%	0.0089
5294	2/24/2009 2:05	73.76	50.50	50.5%	0.0089
5295	2/24/2009 2:10	73.76	50.50	50.5%	0.0089
5296	2/24/2009 2:15	73.94	50.50	50.5%	0.0090
5297	2/24/2009 2:20	73.94	50.50	50.5%	0.0090
5298	2/24/2009 2:25	73.94	50.50	50.5%	0.0090
5299	2/24/2009 2:30	73.94	50.50	50.5%	0.0090
5300	2/24/2009 2:35	74.12	50.50	50.5%	0.0091
5301	2/24/2009 2:40	74.12	50.50	50.5%	0.0091
5302	2/24/2009 2:45	74.30	50.50	50.5%	0.0091
5303	2/24/2009 2:50	74.30	50.50	50.5%	0.0091
5304	2/24/2009 2:55	74.30	50.50	50.5%	0.0091
5305	2/24/2009 3:00	74.30	50.50	50.5%	0.0091
5306	2/24/2009 3:05	74.48	50.50	50.5%	0.0092
5307	2/24/2009 3:10	74.48	50.50	50.5%	0.0092
5308	2/24/2009 3:15	74.48	50.50	50.5%	0.0092
5309	2/24/2009 3:20	74.48	50.50	50.5%	0.0092
5310	2/24/2009 3:25	74.48	49.50	49.5%	0.0090
5311	2/24/2009 3:30	74.48	49.50	49.5%	0.0090
5312	2/24/2009 3:35	74.48	49.50	49.5%	0.0090
5313	2/24/2009 3:40	74.48	49.50	49.5%	0.0090
5314	2/24/2009 3:45	74.48	49.50	49.5%	0.0090
5315	2/24/2009 3:50	74.66	49.50	49.5%	0.0090
5316	2/24/2009 3:55	74.66	49.50	49.5%	0.0090
5317	2/24/2009 4:00	74.84	49.50	49.5%	0.0091
5318	2/24/2009 4:05	74.84	49.50	49.5%	0.0091
5319	2/24/2009 4:10	74.84	49.50	49.5%	0.0091
5320	2/24/2009 4:15	74.84	49.50	49.5%	0.0091
5321	2/24/2009 4:20	74.84	49.50	49.5%	0.0091
5322	2/24/2009 4:25	75.02	49.50	49.5%	0.0091
5323	2/24/2009 4:30	75.02	49.50	49.5%	0.0091
5324	2/24/2009 4:35	75.02	49.50	49.5%	0.0091
5325	2/24/2009 4:40	75.20	49.50	49.5%	0.0092
5326	2/24/2009 4:45	75.20	49.00	49.0%	0.0091
5327	2/24/2009 4:50	75.20	49.00	49.0%	0.0091
5328	2/24/2009 4:55	75.20	49.00	49.0%	0.0091
5329	2/24/2009 5:00	75.20	49.00	49.0%	0.0091
5330	2/24/2009 5:05	75.20	49.00	49.0%	0.0091
5331	2/24/2009 5:10	75.20	49.00	49.0%	0.0091
5332	2/24/2009 5:15	75.20	49.00	49.0%	0.0091
5333	2/24/2009 5:20	75.20	49.00	49.0%	0.0091
5334	2/24/2009 5:25	75.20	49.00	49.0%	0.0091
5335	2/24/2009 5:30	75.20	49.00	49.0%	0.0091
5336	2/24/2009 5:35	75.38	49.00	49.0%	0.0092

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Omega Datalogger: M58400

Maximum Value of Humidity Ratio: **0.0125**
Minimum Value of Humidity Ratio: **0.0098**
Average (Mean) Value of Humidity Ratio: **0.0108**
Average (Mean) Value of Temperature: **66.4785**

#	Date and Time	Temp. (°F)	Humidity (%RH)		Humidity Ratio
790	6/4/2007 2:45	67.28	79.50	79.5%	0.01134
791	6/4/2007 2:50	67.28	79.50	79.5%	0.01134
792	6/4/2007 2:55	67.28	80.50	80.5%	0.01148
793	6/4/2007 3:00	67.28	80.50	80.5%	0.01148
794	6/4/2007 3:05	67.28	79.50	79.5%	0.01134
795	6/4/2007 3:10	67.28	79.50	79.5%	0.01134
796	6/4/2007 3:15	67.28	79.50	79.5%	0.01134
797	6/4/2007 3:20	67.28	79.50	79.5%	0.01134
798	6/4/2007 3:25	67.28	80.50	80.5%	0.01148
799	6/4/2007 3:30	67.28	80.50	80.5%	0.01148
800	6/4/2007 3:35	67.46	80.50	80.5%	0.01155
801	6/4/2007 3:40	67.46	80.50	80.5%	0.01155
802	6/4/2007 3:45	67.46	80.50	80.5%	0.01155
803	6/4/2007 3:50	67.46	80.50	80.5%	0.01155
804	6/4/2007 3:55	67.46	80.50	80.5%	0.01155
805	6/4/2007 4:00	67.46	80.50	80.5%	0.01155
806	6/4/2007 4:05	67.46	80.50	80.5%	0.01155
807	6/4/2007 4:10	67.46	80.50	80.5%	0.01155
808	6/4/2007 4:15	67.64	80.50	80.5%	0.01163
809	6/4/2007 4:20	67.46	80.50	80.5%	0.01155
810	6/4/2007 4:25	67.46	81.00	81.0%	0.01163
811	6/4/2007 4:30	67.64	81.00	81.0%	0.01170
812	6/4/2007 4:35	67.64	81.00	81.0%	0.01170
813	6/4/2007 4:40	67.64	80.50	80.5%	0.01163
814	6/4/2007 4:45	67.64	80.50	80.5%	0.01163
815	6/4/2007 4:50	67.64	80.50	80.5%	0.01163
816	6/4/2007 4:55	67.64	80.50	80.5%	0.01163
817	6/4/2007 5:00	67.64	80.50	80.5%	0.01163
818	6/4/2007 5:05	67.64	80.50	80.5%	0.01163
819	6/4/2007 5:10	67.64	80.50	80.5%	0.01163
820	6/4/2007 5:15	67.64	80.50	80.5%	0.01163
821	6/4/2007 5:20	67.64	80.50	80.5%	0.01163
822	6/4/2007 5:25	67.64	80.50	80.5%	0.01163
823	6/4/2007 5:30	67.64	80.50	80.5%	0.01163
824	6/4/2007 5:35	67.64	80.50	80.5%	0.01163
825	6/4/2007 5:40	67.64	80.50	80.5%	0.01163
826	6/4/2007 5:45	67.64	80.50	80.5%	0.01163
827	6/4/2007 5:50	67.64	80.50	80.5%	0.01163
828	6/4/2007 5:55	67.64	80.50	80.5%	0.01163

CASE STUDY 2

- **Location:** First-floor, one-bedroom unit at three-story wood-framed apartment building in Fremont, CA, constructed atop a reinforced concrete "podium slab" above an at-grade parking garage. Exterior cladding is fiber-cement lap siding integrated with medium-grade aluminum-framed windows.
- **Status:** Painted interior surrounds at the apartment's windows exhibit widespread water staining and spotty mold growth consistent with the bachelor tenant's reports of major condensation problems occurring primarily in the cool morning hours. Again, in accordance with minimum California code requirements, the only forms of mechanical ventilation within the dwelling were a bathroom fan and a little-used exhaust fan at the kitchen range hood. Midmorning spot measurements within the apartment revealed ambient conditions of 66.1˚F and 80.5% RH, which correspond to a humidity ratio of about 0.0110 pounds of water vapor per pound of dry air (reference the field psychrometric table at *Figure 4*).
- **Issue:** After repeated complaints to management of excess humidity, the tenant has elected to vacate the unit after blackish spots of mold began appearing on cereal boxes in his cupboards. Prior to the tenant's departure, a temperature/RH datalogger deployed within his unit for a three-week period has recorded (see *Figure 9*) a minimum humidity ratio of 0.0098 pounds of water vapor per pound of dry air, an average humidity ratio of 0.0108, and a maximum humidity ratio of 0.0125. It has been the author's field-testing experience that this range of minimum-mean-maximum ambient moisture content values is exceptionally high for similar residences in the San Francisco Bay metropolitan area. (It should be noted in *Figure 9* that the RH readings alone, even prior to humidity ratio calculations, are sufficiently high to raise alarms.)
- **Analysis:** Testing at the apartment's floor slab (which also serves as the lid for the parking garage below) revealed elevated moisture content within the concrete and unusually high levels of vapor diffusion into the interior space. However, extensive destructive investigation and water-spray testing at the exterior envelope found no window performance deficiencies and no other exterior source of water infiltration into the concrete floor slab. Therefore, it was reasonable to hypothesize that the source of the moisture that had wetted the floor slab was located within the unit.

  Upon the tenant's complete vacating of the apartment, close inspection of the interior baseboards did reveal visual evidence of plumbing leakage within a wall cavity. Over a multi-year period, this undetected leakage had been absorbed into the concrete floor slab, slowly increasing its overall moisture content and associated vapor diffusion into the ambient air. Visible evidence of the leakage problem had been masked by carpeting, baseboard trim, and a tightly fit clothes washer.[17]
- **Discussion:** A comparison of the humidity ratio data for Case Study 2 (see *Figure 9*) and Case Study 1 (see *Figures 7* and *8*) is informative because the occupants' residences and lifestyles were so closely similar. Here in the San Francisco Bay metropolitan area, the wide and highly variable range of ambient conditions recorded at Case Study 1 (ranging from a minimum humidity ratio of 0.0056 when the unit was unoccupied to an average humidity ratio of 0.0084 when occupied) are typical for poorly ventilated residences in which lifestyle activities are found to be the primary sources of increased interior humidity.

  In contrast, at Case Study 2, the greater range of minimum-mean-maximum ambient moisture documented in *Figure 9* is representative of projects in the San Francisco Bay metropolitan area where there is an unknown reservoir of trapped moisture located somewhere on the property. (Such unexpectedly large reservoirs of water often are located at below-grade and above-grade concrete floors and walls.) In these cases, the key steps to solving the puzzle are:

  1) find the hidden reservoir;
  2) ascertain the process by which the reservoir is releasing unintended moisture into the interior space; and

3) determine the source(s) of water by which the reservoir is being replenished.

CASE STUDY 3

- **Location:** An eight-story residential condominium building in Oakland, CA, constructed atop a street-level parking garage fronted with retail commercial space. Vertically, two-story townhomes are separated by reinforced-concrete floor slabs. Concrete columns at the exterior envelope are integrated with two-story floor-to-ceiling banks of aluminum-framed windows (see *Photo 3*).
- **Status:** Severe vapor condensation conditions (see *Photos 4* and *5*) at these floor-to-ceiling curtain wall banks of glazing occur at many of the townhome units; however, some adjacent units are not experiencing the problem.
- **Issue:** A variety of problematic conditions at the building have led the homeowners' association to initiate construction-defect litigation against the developer; however, due to various legal, logistical, and access considerations, no destructive or intrusive water testing of the building envelope has yet been authorized. Hardwood flooring installed throughout the townhomes blocks nonintrusive moisture metering of the concrete floor slabs. In preparation for the eventual destructive testing necessary to support the litigation, homeowners have allowed temperature/RH dataloggers to be deployed within townhomes experiencing the problematic condensation and also in some of the trouble-free units.
- **Analysis:** The temperature/RH dataloggers confirmed that the ambient air conditions within the condensation-prone units were more humid than the trouble-free units (e.g., compare the summary data in *Figure 10* with *Figure 11*).

The humidity ratio data from the condensation-prone units then was compared with weather data reported by the National Weather Service for a 28-day period consisting of 14 continuous days of no rain, followed by a seven-day period of moderate rainstorms, followed by seven more sunny, rain-free days. The comparative results for two of the condensation-prone units are summarized in *Figure 12*. It is interesting to observe that during the rainy period, the average humidity ratios recorded at the two units increased by 10.26% and 4.55%; however, it is even more interesting that the ambient moisture content of the units continues to increase after the sunny weather has returned.

Note in *Figure 12* that for the seven days of sunny weather after the rains had ceased, the average humidity ratios at the two units were 16.67% and 17.05% greater

than for the extended sunny period prior to the storms. The dataloggers installed at the other condensation-prone units produced similar increases.

- **Discussion:** A reasonable hypothesis for explaining the delayed increases in average ambient humidity ratios is that the moisture content levels of the concrete floor slabs for these townhouses had become elevated during the seven-day series of rainstorms, and then this excess moisture continued to be released via vapor diffusion through the hardwood flooring.

  Further, upon closer observations of the windows and floor slabs (*Photos 6, 7,* and *8*), it is reasonable to hypothesize that the concrete slabs were wetted by window leakage, perhaps at poorly sealed jamb-sill transitions or ineffective flashing or caulking. These hypotheses are speculative, of course; their primary initial value is only to help guide the planning process for future testing.
- **Finding:** In any event, unlike Case Study 1 and Case Study 2, the evidence from the dataloggers strongly supports a preliminary finding that the severity and extent of the interior condensation conditions are closely related to exterior weather events.

Omega Datalogger: M58400

Maximum Value of Humidity Ratio:	0.0104
Minimum Value of Humidity Ratio:	0.0057
Average (Mean) Value of Humidity Ratio:	0.0086
Average (Mean) Value of Temperature:	69.5351

#	Date and Time	Temp. (°F)	Humidity (%RH)		Humidity Ratio
5545	2/16/2008 19:00	75.20	43.50	43.5%	0.00807
5546	2/16/2008 19:05	75.56	43.50	43.5%	0.00817
5547	2/16/2008 19:10	75.92	43.00	43.0%	0.00818
5548	2/16/2008 19:15	76.10	43.00	43.0%	0.00823
5549	2/16/2008 19:20	76.46	42.50	42.5%	0.00823
5550	2/16/2008 19:25	76.64	42.00	42.0%	0.00818
5551	2/16/2008 19:30	77.00	41.00	41.0%	0.00808
5552	2/16/2008 19:35	77.18	41.00	41.0%	0.00813
5553	2/16/2008 19:40	77.36	41.00	41.0%	0.00818
5554	2/16/2008 19:45	77.36	41.00	41.0%	0.00818
5555	2/16/2008 19:50	77.54	41.00	41.0%	0.00823
5556	2/16/2008 19:55	77.72	41.00	41.0%	0.00828
5557	2/16/2008 20:00	77.90	41.00	41.0%	0.00833
5558	2/16/2008 20:05	77.90	40.50	40.5%	0.00822
5559	2/16/2008 20:10	78.08	40.50	40.5%	0.00827
5560	2/16/2008 20:15	77.90	40.50	40.5%	0.00822
5561	2/16/2008 20:20	77.90	41.00	41.0%	0.00833
5562	2/16/2008 20:25	77.72	40.50	40.5%	0.00817
5563	2/16/2008 20:30	77.36	42.00	42.0%	0.00838
5564	2/16/2008 20:35	77.18	42.50	42.5%	0.00843
5565	2/16/2008 20:40	77.36	42.50	42.5%	0.00848
5566	2/16/2008 20:45	77.54	42.00	42.0%	0.00843
5567	2/16/2008 20:50	77.72	42.00	42.0%	0.00848
5568	2/16/2008 20:55	77.90	40.50	40.5%	0.00822
5569	2/16/2008 21:00	78.26	41.00	41.0%	0.00843
5570	2/16/2008 21:05	78.44	40.50	40.5%	0.00837
5571	2/16/2008 21:10	78.44	40.50	40.5%	0.00837
5572	2/16/2008 21:15	78.80	40.50	40.5%	0.00847
5573	2/16/2008 21:20	78.98	40.50	40.5%	0.00853
5574	2/16/2008 21:25	79.16	40.50	40.5%	0.00858
5575	2/16/2008 21:30	79.34	40.50	40.5%	0.00863
5576	2/16/2008 21:35	79.52	40.50	40.5%	0.00868
5577	2/16/2008 21:40	79.70	40.50	40.5%	0.00873
5578	2/16/2008 21:45	79.88	40.00	40.0%	0.00867
5579	2/16/2008 21:50	80.06	40.50	40.5%	0.00884
5580	2/16/2008 21:55	80.06	39.50	39.5%	0.00862
5581	2/16/2008 22:00	80.06	39.50	39.5%	0.00862
5582	2/16/2008 22:05	80.06	38.00	38.0%	0.00828
5583	2/16/2008 22:10	80.06	38.00	38.0%	0.00828

Omega Datalogger: M58158

Maximum Value of Humidity Ratio:	0.0075
Minimum Value of Humidity Ratio:	0.0055
Average (Mean) Value of Humidity Ratio:	0.0064
Average (Mean) Value of Temperature:	65.6402

#	Date and Time	Temp. (°F)	Humidity (%RH)		Humidity Ratio
5545	2/16/2008 19:00	65.30	44.00	44.0%	0.00581
5546	2/16/2008 19:05	65.30	44.00	44.0%	0.00581
5547	2/16/2008 19:10	65.30	44.00	44.0%	0.00581
5548	2/16/2008 19:15	65.30	44.50	44.5%	0.00587
5549	2/16/2008 19:20	65.30	44.00	44.0%	0.00581
5550	2/16/2008 19:25	65.30	44.00	44.0%	0.00581
5551	2/16/2008 19:30	65.30	44.00	44.0%	0.00581
5552	2/16/2008 19:35	65.30	44.00	44.0%	0.00581
5553	2/16/2008 19:40	65.30	44.00	44.0%	0.00581
5554	2/16/2008 19:45	65.12	44.00	44.0%	0.00577
5555	2/16/2008 19:50	65.12	44.50	44.5%	0.00584
5556	2/16/2008 19:55	65.12	44.00	44.0%	0.00577
5557	2/16/2008 20:00	65.12	44.50	44.5%	0.00584
5558	2/16/2008 20:05	65.12	44.50	44.5%	0.00584
5559	2/16/2008 20:10	65.30	44.50	44.5%	0.00587
5560	2/16/2008 20:15	65.12	44.50	44.5%	0.00584
5561	2/16/2008 20:20	65.12	44.50	44.5%	0.00584
5562	2/16/2008 20:25	65.12	44.50	44.5%	0.00584
5563	2/16/2008 20:30	65.12	44.50	44.5%	0.00584
5564	2/16/2008 20:35	65.12	44.50	44.5%	0.00584
5565	2/16/2008 20:40	65.12	44.50	44.5%	0.00584
5566	2/16/2008 20:45	65.12	44.50	44.5%	0.00584
5567	2/16/2008 20:50	65.12	44.50	44.5%	0.00584
5568	2/16/2008 20:55	65.12	44.50	44.5%	0.00584
5569	2/16/2008 21:00	64.94	44.50	44.5%	0.00580
5570	2/16/2008 21:05	65.12	44.50	44.5%	0.00584
5571	2/16/2008 21:10	64.94	44.50	44.5%	0.00580
5572	2/16/2008 21:15	65.12	44.50	44.5%	0.00584
5573	2/16/2008 21:20	64.94	44.50	44.5%	0.00580
5574	2/16/2008 21:25	64.94	44.50	44.5%	0.00580
5575	2/16/2008 21:30	64.94	44.50	44.5%	0.00580
5576	2/16/2008 21:35	64.94	44.50	44.5%	0.00580
5577	2/16/2008 21:40	65.12	44.50	44.5%	0.00584
5578	2/16/2008 21:45	64.94	44.50	44.5%	0.00580
5579	2/16/2008 21:50	64.94	44.50	44.5%	0.00580
5580	2/16/2008 21:55	64.94	44.50	44.5%	0.00580
5581	2/16/2008 22:00	64.94	44.50	44.5%	0.00580
5582	2/16/2008 22:05	64.94	44.50	44.5%	0.00580
5583	2/16/2008 22:10	64.94	44.50	44.5%	0.00580

INTRODUCTORY GUIDELINES FOR ADVANCED INVESTIGATIONS

The primary sources of unintended water within buildings are:

1. "Liquid water from precipitation (rain and melting snow)…;
2. "Liquid water from…plumbing leaks;
3. "Water vapor from the exterior…;
4. "Water vapor from…activities and processes within the building;
5. "Liquid and vapor from the soil adjoining the building;
6. "Moisture built in with the materials of construction…; and
7. "Moisture brought in with goods and people."[18]

As previously noted, the second law of thermodynamics requires, as a fundamental law of the universe, that when two reservoirs of energy (including pools of water vapor) are connected, the greater pool will flow toward the smaller pool until equilibrium is reached. For water vapor, this process of energy flow has been described as follows:

- Moisture tends to move from warm to cold (driven by the magnitude of the thermal gradient) and from more to less (driven by the concentration gradient).[19]

Carefully placed temperature/RH loggers allow us to intercept the flow of this "more to less" and "warm to cold" moisture migration in order to understand its direction and, ultimately, the source(s) of excess moisture. *Figures 13* and *14*, also generated via Excel®, introduce an example of such advanced comparative analysis. In this case, two dataloggers were installed near the front and rear interior elevations at a vacant, unheated commercial space that has been experiencing sporadic interior condensation problems only on hot, sunny days. The graphs present hourly humidity

	14 Days of Sun	7 Days of Rain	7 Days of Sun
Omega Datalogger: M58400			
Maximum Value of Humidity Ratio:	0.0093	0.0100	0.0104
Minimum Value of Humidity Ratio:	0.0057	0.0076	0.0079
Average (Mean) Value of Humidity Ratio:	0.0078	0.0086	0.0091
Omega Datalogger: M55159			
Maximum Value of Humidity Ratio:	0.0096	0.0102	0.0111
Minimum Value of Humidity Ratio:	0.0077	0.0076	0.0085
Average (Mean) Value of Humidity Ratio:	0.0088	0.0092	0.0103

ratio readings for four consecutive days. Consider the daily wave of moisture that pushes inward from the front elevation, peaking about 2:00 p.m. Now consider the same waves at the rear elevation, peaking later in the afternoon. Note the varying amplitudes of these daily waves.

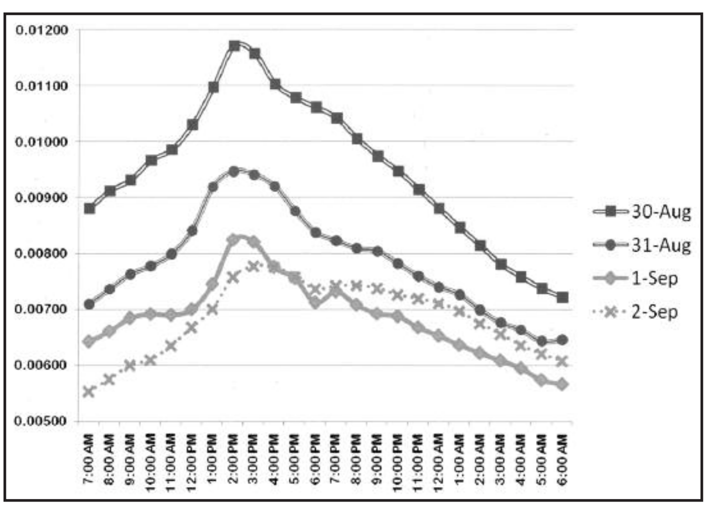
Upon analysis of these two graphs, it would appear that the origin of the moisture waves is located toward the front of the building. Data from a third logger at the building exterior then informs us a reservoir of unintended moisture is situated outside the building. Additional investigation identifies poorly drained, irrigated soil adjacent to nonwaterproofed concrete walls that terminate below grade.

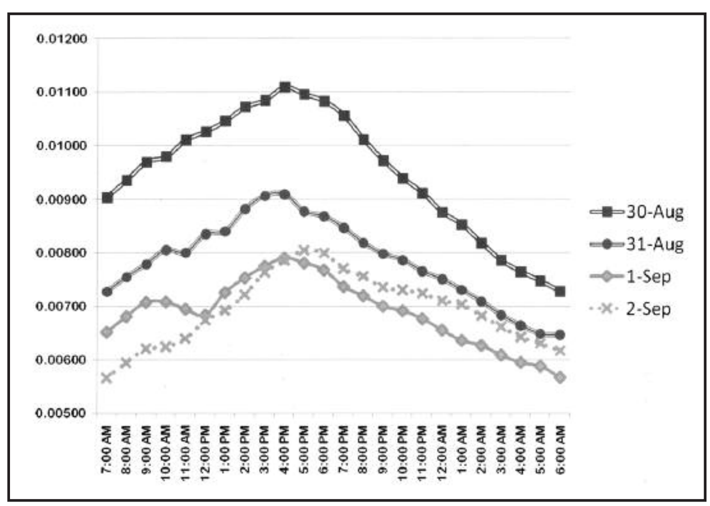
In short, our forensic analysis, including evaluation of humidity ratio data from four carefully placed loggers, led to a preliminary finding that the sporadic sunny weather condensation problem resulted from "solar-driven diffusion" at the south-facing front wall. "Sun-driven moisture is a phenomenon that occurs when walls are wetted and then heated by solar radiation. Upon solar heating, a large vapor pressure difference may occur between the exterior and interior leading to the inward diffusion of moisture."[20]

(The author's full investigation and analysis of these conditions will be summarized in a paper presented at RCI's 25th International Convention and Trade Show in Orlando, FL, in March 2010.)

SUMMARY COMMENTS

The goal of this paper has been to promote humidity ratio measurements as a tool for interior moisture investigations. Building professionals already employ a variety of meters to evaluate moisture-content levels of specific building materials (such as wood or concrete) and assemblies of materials (e.g., low-slope roofing systems). The humidity ratio informs us of the moisture content of





ambient air in much the same manner that commonly used meters inform us of the moisture content of wood and concrete. While solitary humidity ratio measurements may be distorted by transient moisture events, comparative evaluations of extended series of humidity ratio calculations from one or more humidity/temperature loggers can be a valuable source of information for contractors, designers, engineers, forensic investigators, and other consultants.

FOOTNOTES

1. Donald P. Gatley, *Understanding Psychrometrics,* 2d ed., American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA 2005, p. 128: "From an intuitive standpoint, relative humidity can be a misleading indicator of the mass of water vapor in a given volume, space, or parcel of air…"
2. Ibid., p. 125: "…the maximum water vapor content in a given volume rises steeply with temperature, approximately doubling with every 10˚C rise."
3. Ibid., p. 128: "A correct definition of relative humidity for the layperson is: the ratio, expressed in percent, between the mass of water vapor present in a given volume or parcel and the maximum mass of water vapor that the same volume or parcel can hold at the same dry-bulb temperature."
4. Ibid, p. 129: "This demonstrates that stating a relative humidity value without stating or implying the dry-bulb temperature is meaningless."
5. Ibid, p. 11: "…psychrometrics is defined as the science that involves the properties of moist air (a mixture of dry air and water vapor) and the process in which the temperature and/or the water vapor content of the mixture are changed."
6. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., www.ashrae.org
7. Donald P. Gatley, *Understanding Psychrometrics,* 2d ed., American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA 2005, p. 146: "Humidity ratios provide a simple, effective, and most convenient means of accounting for the mass of water vapor in a psychrometric process…by relating it to the non-varying mass of dry air."
8. Ibid., p. 32: "In the first decade of the twenty-first century, most practitioners will rely on psychrometric software. …The chart itself will no longer be used as a graphical solution tool. …The demise of printed psychrometric charts will probably be similar to the demise of the slide rule…"
9. Ibid., p. 29: "A psychrometric chart is based on a specified barometric pressure or elevation with respect to sea level."
10. Ibid., p. 148: "Note that humidity ratio is a function of barometric pressure (or altitude)…"
11. Ibid., p. 148: "The sea level psychrometric chart can be used without significant error for elevations between 400 metres above and below sea level."
12. The second law of thermodynamics requires that when unequal reservoirs of energy are connected, the greater pool will flow into the smaller pool until equilibrium is reached.
13. Donald P. Gatley, *Understanding Psychrometrics,* 2d ed., American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA 2005, p. 129: "The [humidity ratio] in a room is uniform throughout the room. On the other hand, the relative humidity of the air varies throughout the room depending on the temperature of the air or the surface location at which the relative humidity is measured."
14. These data correspond to typical multiweek average humidity ratio readings for apartments in the San Francisco Bay metropolitan area.
15. The author commonly uses the model RHTemp1000 datalogger manufactured by MadgeTech (www.madgetech.com), and marketed by Omega (www.omega.com), or the less expensive HOBO U 10 model manufactured by Onset (www.onsetcomp.com). However, any portable digital device that accurately can record multiple weeks or months of temperature/RH data is acceptable. For example, the RHTemp1000 datalogger can record 21,600 duplex temperature/RH readings at 5-minute intervals during a 75-day period.
16. For this process, the author uses the Get Psyched™ software by kW Engineering of Oakland, CA (www.kw-energy.com/psych.htm); however, other manufacturers of similar software readily can be identified via Web searches.
17. A detailed review of the author's investigation ("Anatomy of a Leakage Investigation at a Concrete Floor Slab,") was published in the July 2008 issue of *Interface*, RCI, Inc.
18. Dr. John F. Straube, "Moisture Control in Buildings," *ASHRAE Journal*, January 2002; also reference seminal publications by Dr. Straube and Dr. Joseph Lstiburek at www.buildingscience.com.
19. Dr. Joseph Lstiburek, "Investigating and Diagnosing Moisture Problems," *ASHRAE Journal*, December 2002; also, reference publications by Dr. Lstiburek and Dr. John Straube at www.buildingscience.com.
20. Dr. Wahid Maref, et al., "Laboratory Demonstration of Solar Driven Inward Vapour Diffusion in a Wall Assembly," National Research Council Canada, 11th Canadian Conference on Building Science and Technology, Banff, Alberta 2007. (Also reference numerous seminal publications by Dr. Joseph Lstiburek and Dr. John F. Straube at www.buildingscience.com.)