EVALUATION OF BUILDING ENVELOPE, HVAC AND LIGHTING SYSTEMS

FOR

NEWPORT TENNIS CLUB

DECEMBER 1, 2011

Submitted by:

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Executive Summary

Yeaton Associates has been asked to analyze the building envelop system, the HVAC system, and the lighting system at Newport Tennis Club, and to make recommendations for upgrading these systems. We were asked to consider upgrades that provide a favorable return on investment, while at the same time eliminate uncontrolled condensation and dripping on the court.

This report begins by examining current energy use. Newport Tennis Club will spend approximately $27,000 on energy during 2012. Electricity comprises one-third of this cost, and is mostly used for court lighting. LP gas purchases will total approximately $18,000 this year. We have used energy modeling software to analyze how this fuel is used in different parts of the building. The model shows that roughly 90% of all LP gas purchased is used to heat the courts, replacing heat lost through court walls and roof, heat lost to the cold floor, and heat lost from uncontrolled ventilation in the space.

In the second section, we describe the physical process of condensation within the roof and wall system. The goal is to identify the necessary features of any roof /wall assembly that successfully prevents condensation and dripping. First, the roof and wall insulation must not allow the temperature at any indoor surface to fall below the "dew point" of the indoor space, otherwise condensation will occur. In an enclosed clay court facility, the dew point is extremely high year-round. This situation requires careful use of thermal insulation around metal structural members like joists, columns, and even fasteners. It also requires that thermal insulation of all surface mount fixtures. Second, the vapor retarder must be highly impermeable, free from penetrations however small, and located very near the indoor surface of the insulation. A major conclusion of this technical evaluation is that the popular **laminated fiberglass/vinyl facing retrofit systems are unsuitable** for clay courts in cold climates such as Newport, NH. The physical conditions at Newport Tennis Club are identical to swimming pool enclosures.

The third section presents three distinct roofing systems which can successfully address condensation and dripping while improving energy efficiency and reducing fuel costs. The first system involves a new roof to be installed above the existing metal deck or new metal deck. For reasons discussed in the paper, this is the most reliable solution. The second and third solutions involve installation of new rigid foam insulation systems below the existing deck. These latter two systems must carefully installed, with attention payed to insulating surface mounted items such as electrical conduit, lighting fixtures, ceiling fans, etc.

The fourth section of the paper addresses HVAC retrofits which help control humidity and ventilation rates for the purpose of controlling mold growth while reducing costs. Mold grows on surfaces when the relative humidity of the air very near the surface exceeds 80%. The analysis shows that during most of the year, mold growth can be controlled through ventilation, assuming one of the recommended insulation systems has been installed. Ventilation during winter can have large heating costs associated with it. Retrofit measures are described for properly controlling the rate of ventilation, and for recovering 'free' energy from the exhaust stream to preheat the incoming ventilation stream. The analysis shows that unfortunately, complete mold control cannot be achieved year-round without some mechanical dehumidification.

The final section examines court lighting. After examining current practices and potential retrofit options, the recommendation is to maintain current practices until the ceiling is replaced with one of higher reflectance, at which time, the current metal halide lamps and associated ballasts and sockets should replaced with the more efficient "pulse-start" metal halide lamps and associated ballasts and sockets, at reduced wattage.

Measure	Installed Cost	Annual Operating Cost Savings	Simple Payback
Court Envelop			
New Roof and Insulation Above Metal Deck		$2,571*	
Rigid Foam Board Insulation Below Existing Deck		$2,571*	
Sprayed Polyurethane Foam Below Existing Deck		$2,571*	
Court Ventilation and Dehumidification			
Control Ventilation Using Motorized Dampers	$12,000	$3,944	3 yrs
Exhaust Energy Recovery System	$25,000	$1,442	17 yrs
Mechanical Dehumidification/Air Conditioning**	$17,000	none	none
Court Lighting			
Retrofit Using Pulse Start Metal Halide	$2,300***	$1,728	1.3 yr

* Fuel savings only. Does not include savings from reduced court maintenance, or potential economic benefits from improved indoor quality, and improved thermal comfort both summer and winter.

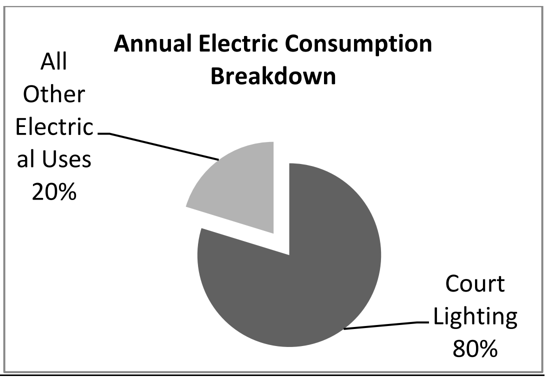
** Required for 100% control of mold.

*** Calculation of labor assumes that fixtures are already being handled as part of ceiling installation. Material cost is the cost of a complete relamping.

Current Electrical Consumption:

Assume:
- $9,000 Total annual electric consumption costs
- **1**080 Watts per court lighting fixture, including lamp and ballast consumption.
- 24 fixtures
- 45 hours per week during September through May (owner-supplied data)
- 15 hours per week during June – august (owner-supplied data)
- $0.142 per kilowatt-hour New Hampshire state average Commercial customer price (Energy Information Agency, USDOE)

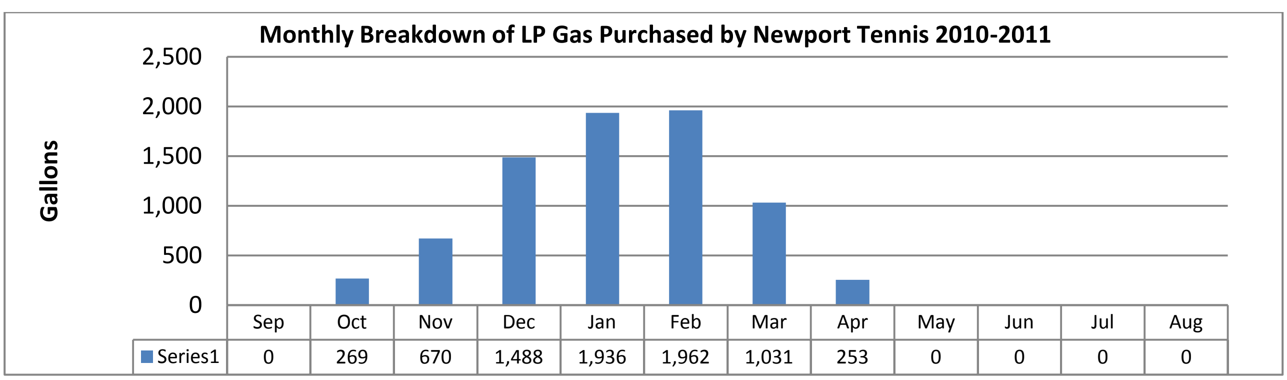
Annual cost for Court lighting: 1080 x 24 x [(45 x 39) + (15 x 13)] ÷ 1000 x 0.142 = $7,177



Current LP Gas Consumption:

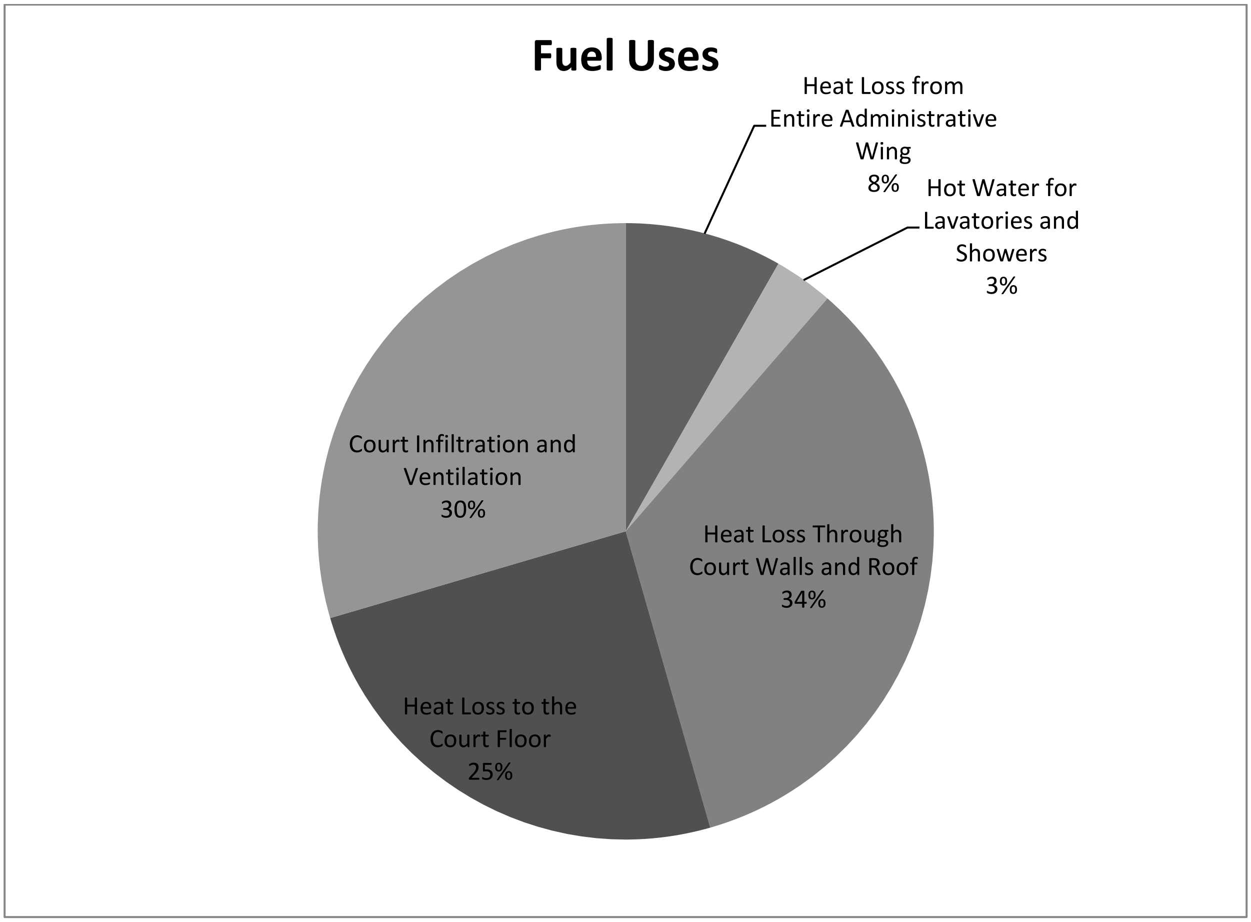
Assume:
- 7610 gallons (previous year consumption)
- $2.50/gal (current rate)

Annual cost for heating at Newport Tennis will be: 7610 x 2.50 = $18,000.



Approximate Breakdown of Heating Needs

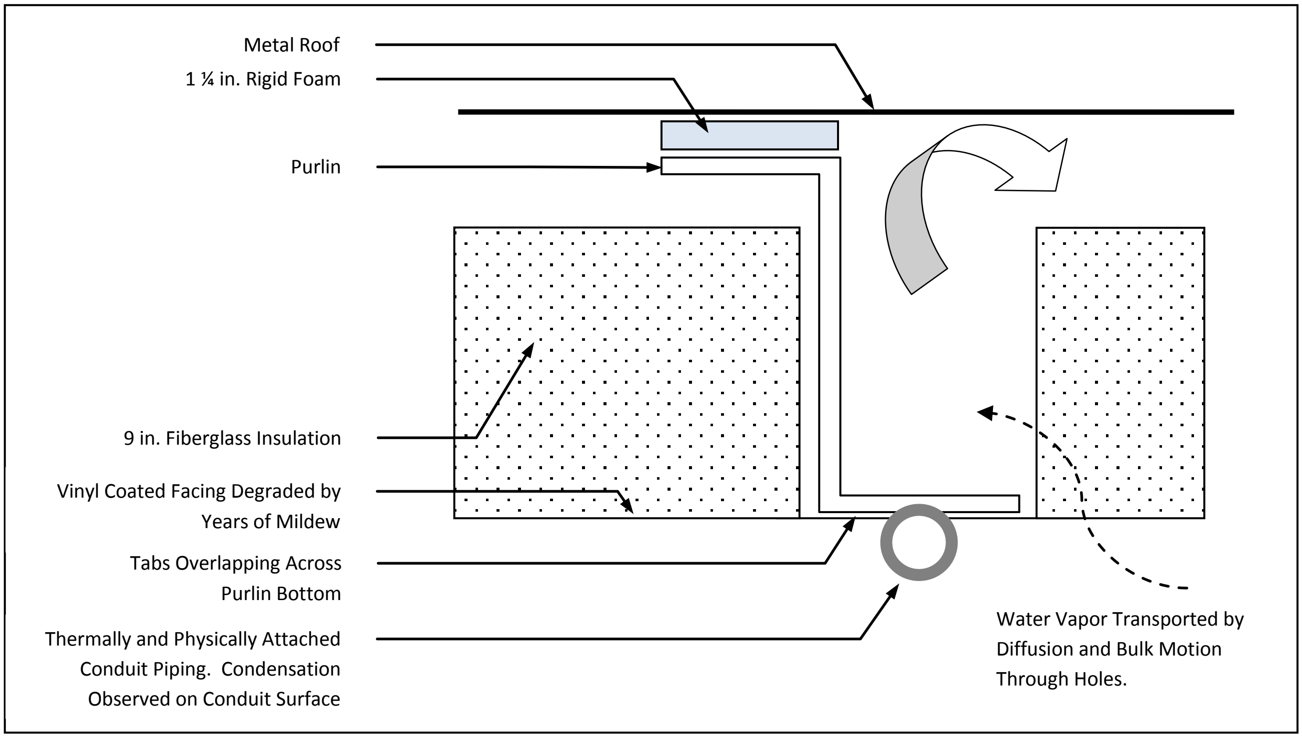
Building energy modeling software (Trane Corp. “Trace 700”) has been used to examine the annual heat loss attributable to the various building components and HVAC processes. Many parameters used in the model are based on experience, and not on exhaustive site investigations of the structure and operation of the building. The input values (assumptions) and resulting reports are available upon request. The results are summarized in the following chart.



Section Summary

This section describing the physical process of condensation within the roof and wall system. Major results are:

- The roof and wall systems must not allow the temperature at any indoor surface to fall below the "dew point" of the indoor space.
- In an enclosed clay court facility, the dew point is extremely high year-round due to court sprinkling.
- This requires careful use of thermal insulation around metal structural members including fasteners, and thermal isolation of all surface mount fixtures.
- The vapor retarder must be highly impermeable, with perm value less than 0.1.
- The vapor barrier must also serve as an air barrier with absolutely no passages for air to move upward into the roof system.
- The vapor barrier must be located at or very near the indoor surface of the insulation



Damage Caused by Condensation

Condensation occurs whenever a surface temperature is below the ambient dew point temperature. Condensation occurs in a variety of ways within the roofing system of Newport Tennis, and is the root cause of several destructive processes:

- Persistent dripping from specific sources causes the degradation and erosion of the court surface directly below.
- Falling water lands directly on members causing a nuisance.
- Once they are established, mold colonies are able to grow on ceiling and wall vinyl facings under a variety of indoor environmental conditions. However, these molds are only able to germinate new spores, and thus establish

new colonies, in the presence of liquid water. Condensation therefore contributes critically to the spread of mildew (a type of mold) within the space.

- Mold colonies that are supported by condensation have biodegraded the vinyl facing, clearly shortening its life.
- Mold on vinyl facings dramatically reduces ambient lighting levels for indirect lighting systems such as the one installed in Newport Tennis, requiring increased lighting energy consumption.
- Mold is ugly and potentially unhealthy.

Absolutely No Thermal Bridging

A 'thermal bridge' is any component in the roof assembly which allows heat to readily conduct between the underside metal roof and the interior space. The roof may have nine inches of insulation over most of its area, but the metal purlin is a highly effective conductor of heat, and although it is tall and thin in cross-section, heat conducts quickly away from the bottom flange toward the top flange during winter, chilling the entire purlin. We have said that condensation forms on any surface whose temperature is below the dew point of the air surrounding. This condition is satisfied on the bottom surface of the bottom flange which is adjacent to the high dew point interior space (Dew point = 50 F: See below). The condition is also satisfied on the metal conduit tubing which is thermally connected to the flange.

> A no-drip solution must involve absolutely no surface area – however small – adjoining the interior space, where the surface temperature falls below indoor dew point, at any time during the year.

Interior Dew point Temperature

If we imagine closing off all outdoor air ventilation, then Newport Tennis becomes a closed container of air lying above an expansive, saturated 50 F surface (direct measurement). We know it is saturated, because surface granules are water-coated and stick to your hand, and because if they do not stick, the maintenance staff adds water to make it so. Water vapor continually evaporates from the floor surface, as a vapor, and will continue to do so as long as the density of water molecules in the space over the floor is less than the density of water molecules adjacent to the saturated floor. When the two densities are the same, then we say that the air in the space is in 'equilibrium' with the moist 50 F saturated surface, i.e. its 'dew point temperature' is 50 F. Dew will condense on a glass of beer that is 49 F in such a space, but not on a 51 F glass.

In the Mold section, we will examine ways to reduce the dew point of the space through ventilation and/or mechanical dehumidification. We state the result here, that even for very aggressive dew point reduction efforts, any structural metal that passes from above the insulation layer to the occupied space below the insulation layer will have a surface temperature that is less than then the dew point in the space at certain times of the year, unless it is adequately thermally insulated from the space.

> A no-drip retrofit solution at Newport Tennis must involve a continuous thermal insulation system that completely thermally isolates metal elements of the roof system from the interior space.

Required R-value for Preventing Thermal Bridging

We recommend that the insulation system be designed to handle the no-ventilation scenario. Thus the assumed indoor dew point in the following calculation is 50F. This enters the equations as a requirement that the temperature of the indoor insulation surface be 50F, or more conservatively, 53 F.

Assume:

- Insulation surface temperature : 53 F
- Design outdoor air temperature = -12 F (National Weather Service)
- Indoor air temperature 55 F (Staff)
- Thermal resistance of surface air boundary layer: 0.62 hr-sf-F/Btu (ASHRAE Fundamentals 2009)

From the basic heat conduction equation:
R = 0.62 x (53 – (-12)) ÷ (55 – 53) = 20.15 hr-sf-F/Btu

The required R-value is 20. This is equal to 6.0 inches of fiberglass, 3.0 to 4.0 inches of sprayed polyurethane foam, 3.0 to 3.5 inches of polyisocyanurate insulation boards, or 3.5 to 4.0 inches of extruded polystyrene insulation boards.

Solution Requirement #2: A vapor retarder must lie entirely below the insulation, and must be continuous

The purpose of a vapor retarder is to block moisture from penetrating into a wall or ceiling where it will encounter a surface temperature below the dew point temperature and condense. At Newport Tennis, frigid temperatures exist on metal surfaces above the insulation system, because of heat conduction up through the metal roof in winter, and because air is able to move about and distribute frigid air above the membrane (see Figure #1).

Moisture can enter into the roof assembly in at least two ways.

1. Moisture can diffuse through the vinyl coated facing of the laminated ceiling system. This process accelerates with time as pernicious mold degrades the vinyl; coating. This is shown in Figure #1 as “Moisture diffusing through the vinyl facing”.
2. Moisture is transported with moving air the passes upward through small openings in the vinyl facing. This motion is caused by natural warm air rising, and is induced by wind outside the building.

> A no-drip retrofit solution at Newport Tennis will involve a continuous, durable vapor retarder, free from mold degradation, and with all penetrations gasketed or foam-sealed. Seams must be continuously sealed with splicing tape or glue.

In many buildings, the moisture retarder can be successfully sandwiched within the interior of the roof assembly, with insulation on either side. This is NOT true at Newport Tennis. As moisture diffuses into the assembly, it will condense at the first point where the temperature is below the dew point. With indoor dew points at or near 50 F, the location within the insulation where 50F occurs is literally millimeters in from the indoor surface of the insulation.

> A no-drip retrofit solution at Newport Tennis will involve a vapor retarder that is positioned at the indoor surface of the insulation.

Section Summary
Three roofing systems are discussed which can successfully address condensation and dripping while improving energy efficiency and reducing fuel costs. Key recommendations are:

- Option #1: Install new roof above the existing metal deck or a new metal deck.
- Option #2: Install a new moisture barrier and insulation system below the existing standing seam metal roof, using rigid foam insulation boards.
- Option #3: Spray polyurethane foam on underside of metal deck and purlins.
- Appearance coverings are required for all of these systems, for aesthetic reasons, and because the indirect lighting system works most efficiently with high ceiling reflectance values. Recommendations for specific appearance coverings have not been included in this report.
- Surface mounting of wall and ceiling fixtures must be done in a way which avoids thermal shorts created by fasteners. A recommendation is included.
- By improving the overall R-value to R30, Newport Tennis will save an estimated $2,600 per year.

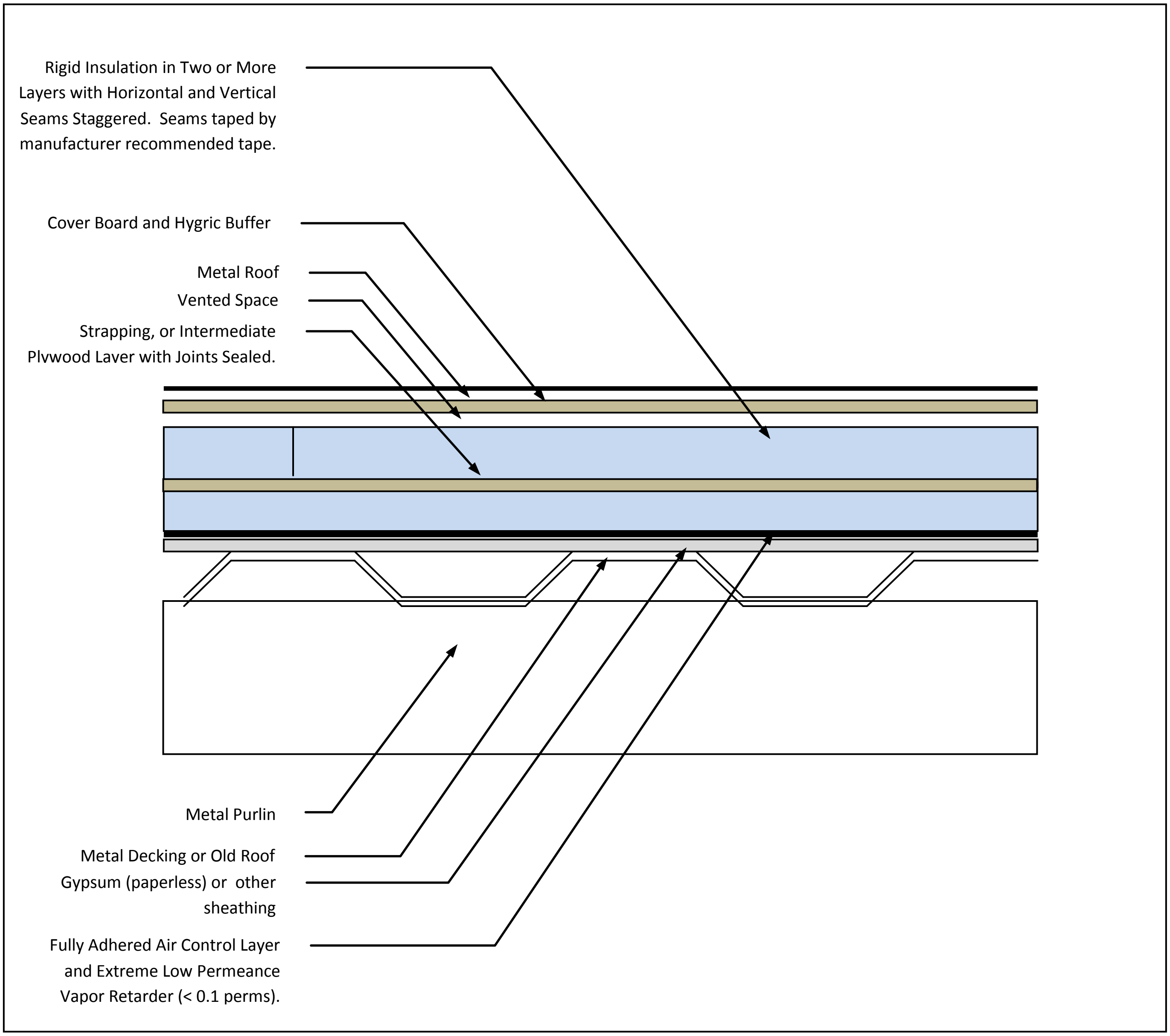
The conditions that have been described above for clay courts in Northern New England are precisely the same conditions that engineers and architects encounter when designing a natatorium (swimming pool hall) enclosure. Specifically, year-round, constant, very high interior dew point values tend to constantly drive moisture into wall and ceiling cavities where it condenses on colder surfaces. Meanwhile, condensation forms on all wall and ceiling components, of any size, where the surface temperature falls below indoor ambient dew point.

Ceiling systems which are marketed as tennis court retrofit systems are appropriate for low-humidity spaces. They are not suitable for a clay court system in Northern New England, because the vapor retarder system is not suitable for extremely high vapor pressure gradients, and thermal shorts are very difficult to eliminate.

In order to achieve the goal of eliminating condensation and dripping, Newport Tennis Club must purchase and install a well-engineered natatorium ceiling and wall system.

Recommendation #1: Entire New Roofing System.

Natatorium retrofits in metal buildings are rare. Indeed, projects that are presented in publicly available literature involve removal of the roof, in order to construct the building correctly. Correctly constructed natatorium roof systems with steel structure virtually always involve placing all structural elements (joists, columns, purlins, etc.) and all services (HVAC, electrical, etc.) ***entirely inside of*** the thermal insulation layer, and ***entirely inside of*** the vapor retarder. The obvious reasons for this are that penetrations in the vapor retarder are very difficult to seal. Structural elements which pass through eh insulation create thermal shorts. Surface mount fixtures such as pendant lights, and destratification fans are difficult to install on mechanically stiff and strong bases with no thermal breaks.



Notes:

1. R-Value: In the diagram, the rigid insulation should have a total R-value of at least 30.
2. The existing insulation must be removed to ensure that the vapor barrier lies on the warm side of the dew point location within the roofing system
3. The intermediate plywood serves as a screw attachment for the metal roof, where the screw length is selected such that they penetrate only to this layer, and do not create a thermal short by penetrating through to the metal deck.
4. The vented space allows water which does enter the roof to eventually leave the assembly before dripping.
5. The current roof is in good shape.
6. It is not recommended that this be considered with membrane roofs. Metal roofs are recommended because of the added assurance that snow loads will be distributed evenly, which is a structural safety issue.

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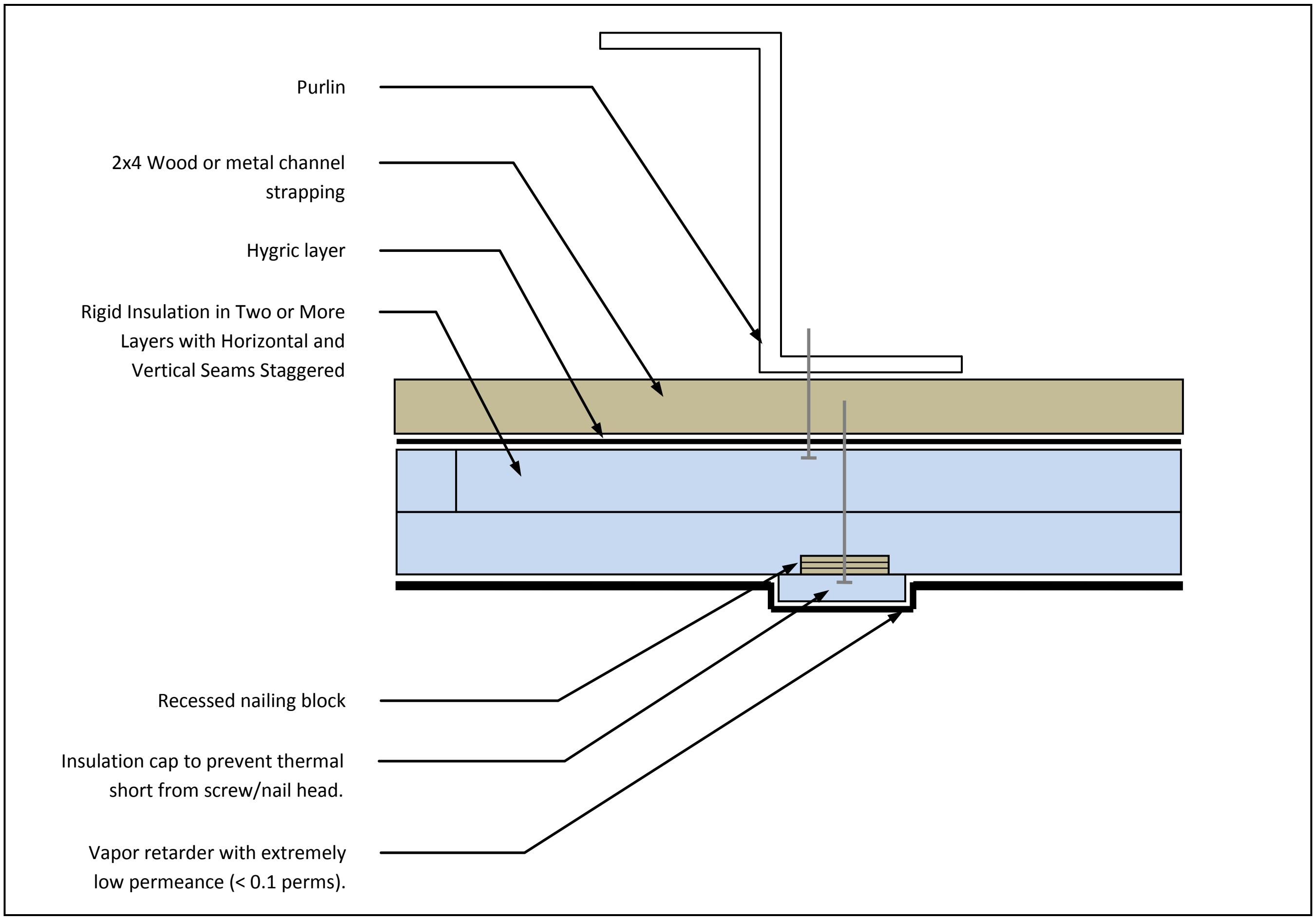
Recommendation #2: Moisture Barrier and Insulation Systems Below Structural Metal Using Foam Boards.

We repeat from above: correctly constructed natatorium roof systems with steel structure virtually always involve placing **all** structural elements (joists, columns, purlins, etc.) and all services (HVAC, electrical, etc.) ***entirely inside of*** the thermal insulation layer, and ***entirely inside of*** the vapor retarder. If Newport Tennis deems it necessary to install these layers below the structure, however, then recommendations #2 and #3 will significantly improved condensation control within the building.



Notes:

1. Fasteners are not shown. In this scheme, the strapping is screwed to the purlin. The insulation boards are held up by the nailing block. A screw or nail is driven through the nailing block into the strapping.
2. Strapping should be sized, and on-center spacing should selected so as to prevent sagging of the assembly, and to support the insulation manufacturer's recommended nailing schedule, accounting for the added weight of the thermal barrier.
3. Hygric layer allows vapor to pass, while introducing 'wicking' to disperse droplets in the event they form. Moisture will eventually leave the system due to air movement above the insulation system.
4. Vertical seams in the respective insulation layers should be horizontally offset by at least 6 inches.
5. All seams should be taped and sealed with manufacturers' recommended sealing materials to retard air and moisture migration.
6. Vapor retarder should be continuously adhered, or spray or roller applied. Note that most vapor retarders do not have the low permeance required for this application.

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7. The existing system should be removed, because the existing vinyl facing will form a vapor barrier on cold side of the dew point location within the system. Any moisture that does happen to reach it from below will condense on the vinyl. Installing the hygric layer, and densely slashing the vinyl, are two preventative measures if the existing system is to remain.
8. Foam plastic insulation products have stringent code requirements governing their use for the prevention of fire. See 2009 IBC Chapter 26. Consult fire code enforcement official for approved thermal barriers and ignition barriers. In some cases, laminated facings may be sufficient.

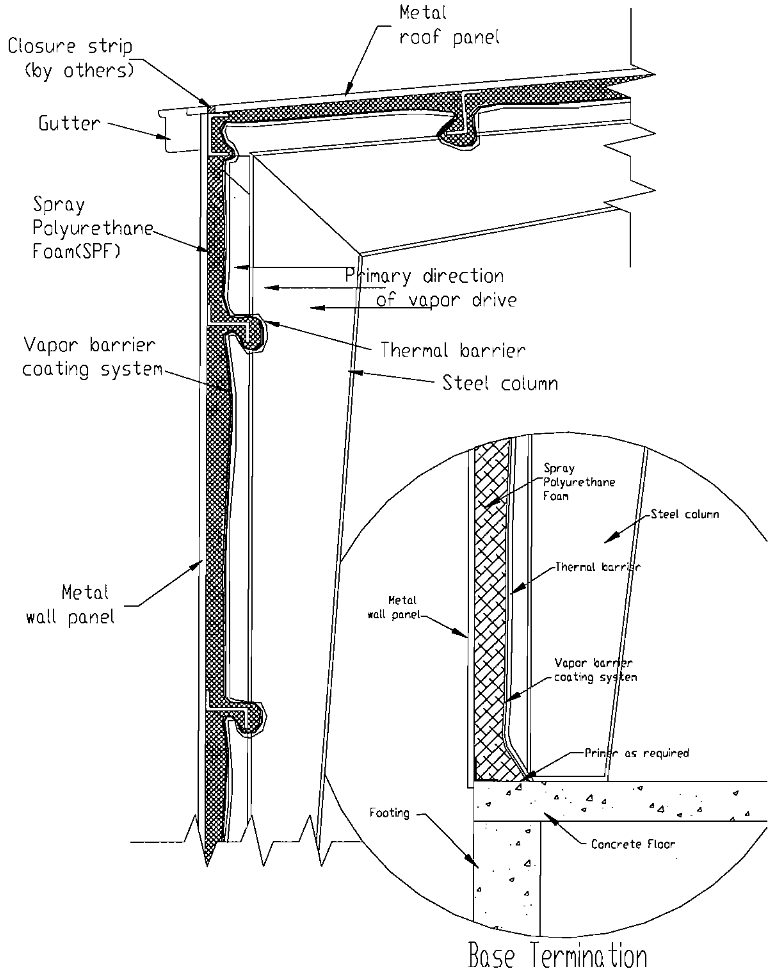
Recommendation #3: Moisture and Thermal Barrier System Below Structural Metal Using Only SPF.

Spray Polyurethane Foam (SPF) can be applied to all surfaces, providing an effective air barrier, and eliminating thermal shorts wherever it is applied in a continuous coating of five (5) inches or more.

Notes:

1. Start by completely removing the existing insulation system.
2. When applied to interior surfaces, the PSF must be covered with a 15 minute thermal barrier for fire protection. Various types of thermal barriers are available which may be sprayed, troweled or mechanically fastened to the foam.
3. Moisture Permeability - SPF is available in many formulations, all with differing resistance to water vapor diffusion. Permeability values are generally around 2.0 perms- inch (Divide by thickness in inches to obtain perms). Thus, 4 inches is required for perm = 0.5. This is adequate for a standard occupancy building, but in the case of strong, constant vapor pressure gradients, this is not adequate. Moreover, by applying foam to a relatively impermeable metal surface which is located on the cold side of the assembly , it seems probable that constant outward diffusion through the foam will cause the accumulation of water at the foam/metal interface, leading to freeze-thaw cycling and the breakdown of the system. Therefore, a flawless vapor retarder with extremely low per rating (< 0.1) must be applied to the indoor surface of the foam. This can be applied as a spray or with a brush. The next page shows a schematic system. The drawing is from the Spray Urethane Foam Alliance.
4. When SPF is applied to a substrate which shifts dimensionally, cracks in the SPF potentially can develop. Metal buildings have the potential to undergo dimensional shifts. If cracks develop in the SPF due to shifting building parts, they must be repaired immediately, because the steady vapor pressures in this building will cause moisture migration into the opening and condensation on cold revealed surfaces no matter how small, and nuisance dripping can result.

RECOMMENDED DETAILS
FOR INSULATING METAL BUILDINGS



VAPOR DRIVE TOWARD OUTSIDE
SPF APPLIED ON INTERIOR

Appearance Coverings

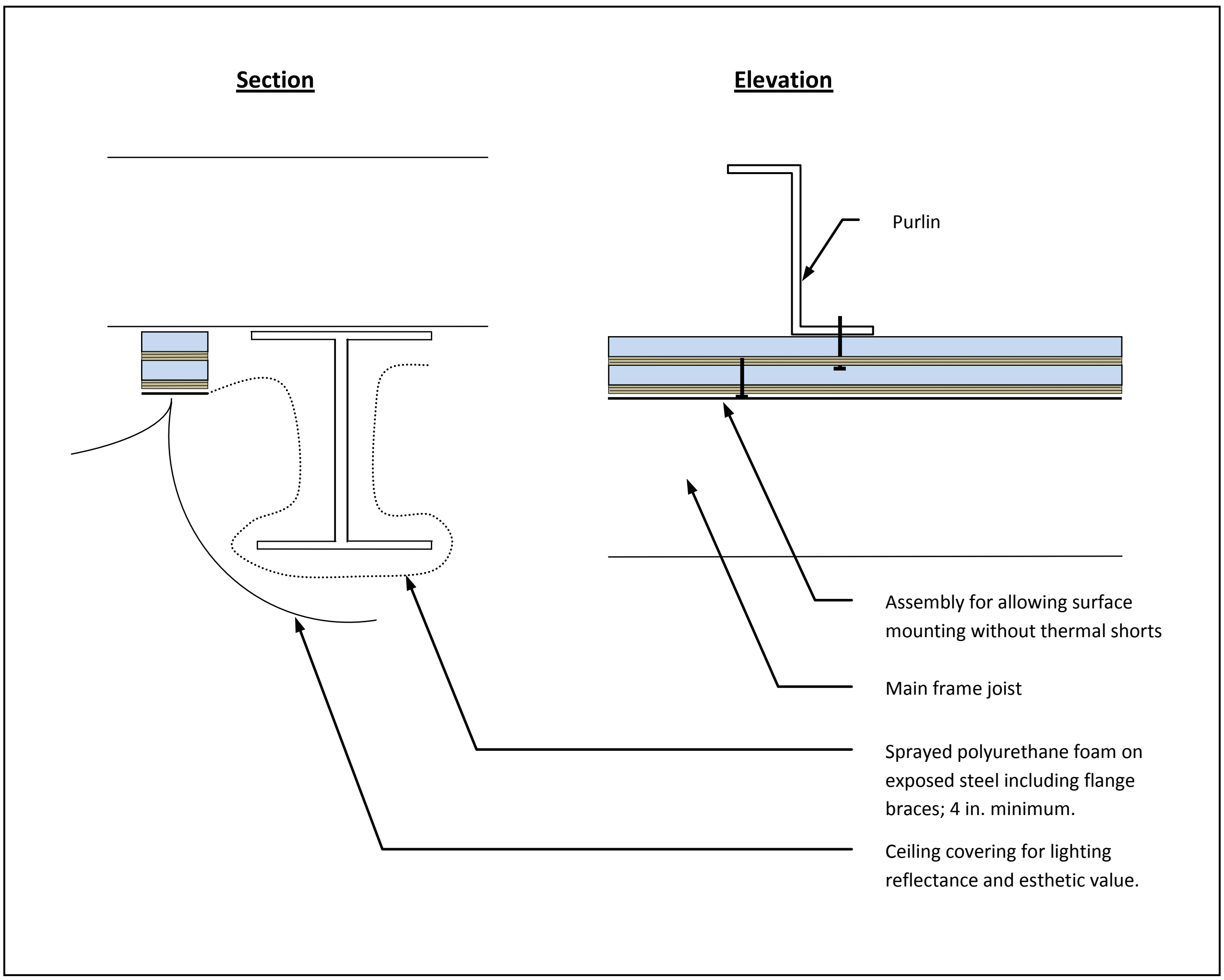
Most of the insulation systems described above do not provide a white, reflective surface which is necessary for the operation of the indirect lighting system in Newport Tennis. Therefore, an additional system must be installed, either as a draped sheet, an adhered sheet, a liquid applied membrane, or rigid panel. Products that are paintable and that may be power washed are desirable.

> The systems recommended in this report all distinguish between the appearance covering and the vapor retarder system. In this way, the appearance covering can be selected, maintained and replaced without impacting the integrity of the low-permeance vapor retarder.

Recommendation #2 requires a continually adhered vapor retarder, which may be an adhered film, or may be a spray or roller applied product. In either case, the final surface of the vapor retarder membrane will be quite flat and smooth, and may be painted. Check with manufacturer for material compatibility.

Surface Mounting

Electrical conduit, lighting fixtures, and destratification fans require mounting. The appearance covering system just described may also require mechanical fastening. By screwing through to the metal purlin, a thermal short is created which must be avoided . The figure below illustrates one example of a constructed base for surface mount fixtures.



Savings

The following calculation estimates the savings from the improved R-value of the new system. Note that the R-value of the existing system is the weighted average of all the metal and its temperature and surface area, as well as the 9-inches of fiberglass between the metal .

Assume:

- R-30 new insulation system.
- R-14 existing wall insulation when thermal shorts are accounted for.
- 9,980 ft^2 total wall area
- 14,400 ft^2 area of ceiling
- R-19 Existing roof
- 4600 HDD base 55 for Concord (hourly weather data)
- 0.75 net efficiency of propane unit heaters
- $2.50 / gallon propane
- 92,333 Btu/gallon Heat Content of propane.

Annual Savings: [(9980 ÷ 14) + (14400 ÷ 19) – (9980 ÷ 30) – (14400 ÷ 30)] x 4600 x 24 ÷ 0.75 ÷ 92333 x 2.5 = $2571.

Humidity and Ventilation Control

Controlling Humidity in Order to Control Mold Growth

Mold growth is undesirable for several reasons:

- Mold has biodegraded the vinyl facing, clearly shortening its life.
- Mold on vinyl facings dramatically reduces ambient lighting levels for indirect lighting systems such as the one installed in Newport Tennis, requiring increased lighting energy consumption.
- Mold is unattractive and potentially unhealthy.

At Newport Tennis, the vinyl covering of the laminated insulation system is discolored by a mildew known as 'black' mildew. Mildew is a class of mold. Mold can grow on nearly any surface, but can only grow under specific temperature and humidity conditions. These conditions can be summarized using the concept of relative humidity.

> Molds colonies can grow on a surface when the air immediately above the surface has a relative humidity over 80%. Under 80%, they do not grow. Yeaton recommends that the relative humidity in the general space be maintained at 65%, while the temperature continue to be maintained at 55 F. This corresponds to a dewpoint of 43.5 F.

> Note that with the existing insulation system, thermal shorts create conditions for mold growth on many surfaces during winter, even at the proposed relative humidity values. Mold control at Newport Tennis requires BOTH a proper insulation system as well as humidity control.

In the following tables, we have chosen representative values of air and surface temperatures to illustrate the fact that, as long as the relative humidity set point of 65% is maintained, and as long as thermal shorts are eliminated by a new insulation system, then wintertime mold growth is arrested. Unfortunately, in summertime, the potential for mold growth exists even after the insulation upgrade.

Typical Operating Conditions and Mold Growth Potential. Assumes No Mechanical Dehumidification			
	Summer Design Day	Summer Night	Winter Design Day
Outdoor Air Temp	88	70	-12
OA dewpoint	65	64	-13
Indoor Dew Point	60	59	43.5**
Purlin Surface Temp After Insulation Retrofit	72	62	53
RH at Purlin Surface After Insulation Retrofit	70	93	70
Mold Potential	marginal	yes	no
Condensation Potential	no	no	no

** This is controlled.

The following discussion assumes that insulation retrofits are in place, because without these retrofits, any discussion of controlling mold by other means is moot.

Humidity Control Option #1: Controlled ventilation

Currently, east and west gable end ventilation openings are left fully open constantly throughout the year. Each has an area of approximately 32 ft^2. The west gable opening is equipped with two propeller fans which exhaust air whenever a space humidistat senses relative humidity levels above setpoint. It is reported that the fans seldom come on during winter, and our site visit confirmed this.

Concerns:

- At times during winter, the humidistat is satisfied and the exhaust fans remain off, while large amounts of frigid air continue to pour through the openings, creating an unnecessary heating load. Using the building energy model, we infer that an average of 1,450 cfm flows through these very large openings, under the influence of incident wind and buoyancy forces in winter.
- During summer, there are many hours when the RH exceeds the humidistat setpoint and the fan is energized, even though the dewpoint of the outside air actually exceeds the interior dewpoint. Dehumidification through ventilation only occurs when the dewpoint (which measures "absolute humidity") of the outdoor air is less than the dewpoint of the air it displaces.

Recommendation:

- Place a motorized damper in each of the gable end opening. Dampers shall be insulated, low-leakage type with parallel blades. Remount the fans as necessary. Fans shall be interlocked with the damper actuator. When the fan is off, the damper shall be 100% closed. When the fan is energized, and damper shall be 100% open.
- Replace the current humidistat control with one indoor sensor and one outdoor sensor. Fans shall operate only when both of the following conditions are true:
  1. The indoor dewpoint is greater than the setpoint (43.5F, adj.)
  2. The indoor dewpoint is greater than the outdoor dewpoint.
- If fan motor noise is an issue, then more sophisticated control can continually modulate the louvers without energizing the fan at first, opening exhaust and intake louvers in tandem, in proportion to the difference between sensed indoor dewpoint and setpoint. The fan would energize only when the louvers were fully opened.

Assume:

- 1,450 cfm current ventilation/infiltration rate
- 1.08 Btu/hr/F/cfm of air
- 4600 HDD base 55 for Concord (hourly weather data)
- 0.75 net efficiency of propane unit heaters
- $2.50 / gallon propane
- 92,333 Btu/gallon Heat Content of propane.
- Total water removed by ventilation = total sprinkler water
- Total weekly sprinkler water during heating season= 194 gallons per week
- 8.3 pounds per gallon for water
- 0.00045 lbm/cfm absolute humidity of exhaust air (for 43.5 dewpoint setpoint)
- 0.00015 lbm/cfm absolute humidity of entering air (weighted average using weather data analysis)

Current annual cost for ventilation: 1450 x 1.08 x 4600 x 24 ÷ 0.75 x 2.50 ÷ 92333 = $6,229

Total sprinkler water added = water vapor transported out – water vapor transported in.
194 x 8.3 = { (0.00045 x cfm) - (0.00015 x cfm) } x 60 x 24 x 7
Solving, the weighted average required exhaust rate is: 532 cfm

Annual cost for ventilation after retrofit: 532 x 1.08 x 4600 x 24 ÷ 0.75 x 2.50 ÷ 92333 = $2,285
Annual cost savings from controlled ventilation: $6,229 - $2,285 = $3,944.

Humidity Control Option #2: Heat Recovery

Air-to-air heat recovery devices can be used to recover energy from the exhaust air, using that heat to warm the incoming supply stream. Every BTU of heat recovered in this way is a BTU that is not required from burning LP gas. This analysis assumes that properly controlled motorized dampers are installed.

Concerns:

- The moist leaving air can be chilled so much as it passes through the heat exchanger that it freezes on the heat exchanger surfaces. This must be avoided using a control strategy.
- Propeller fans like the exhaust fans at Newport Tennis are used to move high air volume against low or no static pressure drop. By placing a heat exchanger in front of the fan, the flow could be substantially reduced. This issue is addressed by placing the heat exchanger only in front of one of two inlet openings and one of the two exhaust openings, using these in winter only when flow rates required for humidity control are less than ¼ the required summer flow rates.

Recommendation:

- Install ‘run-around’ heat exchange system consisting of two heat exchangers, piping and pump for circulating a glycol solution between the coils, and controls.
- Dedicate one exhaust fan opening, and one outdoor air intake opening for wintertime use. The run-around pump operates whenever these louvers are opened.
- A manual switch changes the choice of louvers and fans seasonally.

Assume:

- 50% system effectiveness
- 532 cfm weighted average ventilation rate
- 27.4 F Seasonally weighted average outdoor air temperature (Concord, NH climate data)
- 1.08 Btu/hr/F/cfm of air
- 30 Week heating season
- $2.50 / gallon propane
- 92,333 Btu/gallon Heat Content of propane.

Effectiveness = $(T_{ENTERING} – T_{OD}) / (T_{ID} – T_{OD})$
0.5 = $(T_{ENTERING} – 27.4) / (55 – 27.4)$
Solving, the seasonally weighted average entering air temperature is: 41.2 F.

Annual Savings: 532 x 1.08 x (41.2 – 27.4) x 24 x 7 x 30 ÷ 0.75 x 2.50 ÷ 92333 = $1,442

Humidity Control Option #3: Mechanical Dehumidification

The above table shows that summertime conditions will occur when ventilation strategies cannot prevent mold growth. This occurs when outdoor dewpoint, or 'absolute humidity', is higher than the indoor dewpoint, and ventilation only draws in an added surplus of moisture. The control logic involving both indoor and outdoor sensors described in Option #1 will help a great deal in minimizing conditions for mold growth. However, if Newport Tennis wishes to have insurance that mold growth is completely arrested, they must mechanically dehumidify during summer.

Recommendation:

- Install a floor-standing dehumidifier.
- Condensate can be handled using a condensate pump, allowing the unit to be placed between courts along the wall. The unit could be placed along the administrative wall and permanently piped to a drain.
- Size the unit to handle 100% of the dehumidification required to maintain indoor relative humidity setpoint.

Assume:

- $0.142/kWh marginal electricity rate
- 3.412 Btu/hr per Watt
- 3.0 COP dehumidifier efficiency
- Total weekly sprinkler water during heating season= 194 gallons per week
- Total weekly sprinkler water during summer season= 345 gallons per week
- 8.3 pounds per gallon for water

Sizing to handle summer watering load (gallons per hour):
345 gal/wk ÷ 7 d/wk ÷ 24 h/d = 2 gallons per hour (8 liters per hour @ 65 % rh, 15 C)

Summer day dehumidification energy cost: 2 gal/hr x 8.3 x 980 ÷ 3.0 ÷ 3.412 ÷ 1000 x 24 x 0.142 = $5.44 per day

Tennis Court Lighting Retrofit Analysis

Sylvania Metal Halide Lamp Model	Catalogue Number	Number of Fixtures	Watts per Fixture	Total kW	Annual Operating Hours	Annual Operating Cost @ $0.142/kWh	Initial Lumens	Lumens after 40% of life	Expected Life Hours
MetalArc Pulse Start	M1000/PS	24	1080	25.920	1950	7177	110,000	96,000	15,000
MetalArc Super	MS1000/BD	24	1080	25.920	1950	7177	115,000	92,000	18,000
MetalArc Supersaver	M950/SS	24	1030	24.720	1950	6845	103,000	80,000	18,000
MetalArc Pulse Start	MS750/PS/BD	24	820	19.680	1950	5449	78,000	67,000	16,000

Conclusions:

1. Newport Tennis currently buys the MetalArc Super, MS1000/BD, which is a high performance lamp, with high expected life.
2. The MetalArc Super depreciates faster than the Pulse Start series, offering less light as time goes on. The Pulse Start series claim to fame is their persistent light output. Therefore, Newport Tennis should eventually switch to the pulse start technology.
3. Our recommendation is to continue for a year or two with the lamps you purchase now, while the existing ceiling system is in place. Switching to pulse start lamps will involve a complete relamping, which involves expensive labor. Relamping when the ceiling is upgraded, and workers are already handling the fixtures, is a more efficient use of labor. Also, until the ceiling is upgraded, the current reflectivity (whiteness) of the mildewed ceiling is so low that reduced wattage lamps would not provide adequate illumination levels at the court surface.
4. When the ceiling is refurbished and its reflectivity improves, Yeaton recommends switching to the MetalArc Pulse MS750/PS/BD. We estimate that the ceiling reflectivity will change from its current value of, say, 40-45%, to a new value of approximately 65-70%, i.e. improve by 50%. Therefore, the net delivered light will be the same or even brighter with the 750 Watts and a new ceiling, compared with today's light levels delivered by the 1000 Watt lamps and the mildewed ceiling.