Living Wall Retrofit

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Prior to 2003, the western part of the Montréal–Pierre Elliott Trudeau International Airport terminal was humidifed by injecting steam into the fresh air-handling unit supply air duct. After the commissioning of a new state-of-the-art central plant in 2003, steam-generating boilers were phased out, steam pipes were dismantled, and consequently the terminal's western part was left without humidification in winter.

As shown in *Figure 1,* in extreme winter conditions, when outdoor air dry-bulb temperature is at –18°F (–28°C) and its relative humidity is at 100%, heated fresh air (*without humidification*) will leave the heating coil at a very low relative humidity.

The terminal's indoor relative humidity was monitored during the 2014–2015 winter and found to be between 12% and 14%, which is far below the minimum 20% relative humidity required by the Occupational Health and Safety Regulation in Quebec.[1] Passengers and employees complained about discomfort.

The terminal's western part is served by a dual-duct variable air volume (VAV) HVAC system. The system is comprised of a dedicated fresh air-handling unit and another recirculating air-handling unit. The HVAC system's configuration is shown in *Figure 2.*

Problem-Solving Alternatives

In light of the above, the engineering and architecture team studied three alternatives to improve the western part of the terminal's comfort and passenger/employee satisfaction level:

- **Alternative 1:** Install a steam humidifier for the dedicated fresh air-handling unit;
- **Alternative 2:** Install an evaporative humidifier for the fresh air-handling unit; or
- **Alternative 3:** Install a living wall and a biofilter equipped with a return air plenum that can be connected to the nearby air-handling unit's return duct.

Adding an evaporative humidifier to the existing dedicated fresh air-handling unit requires extra space in the

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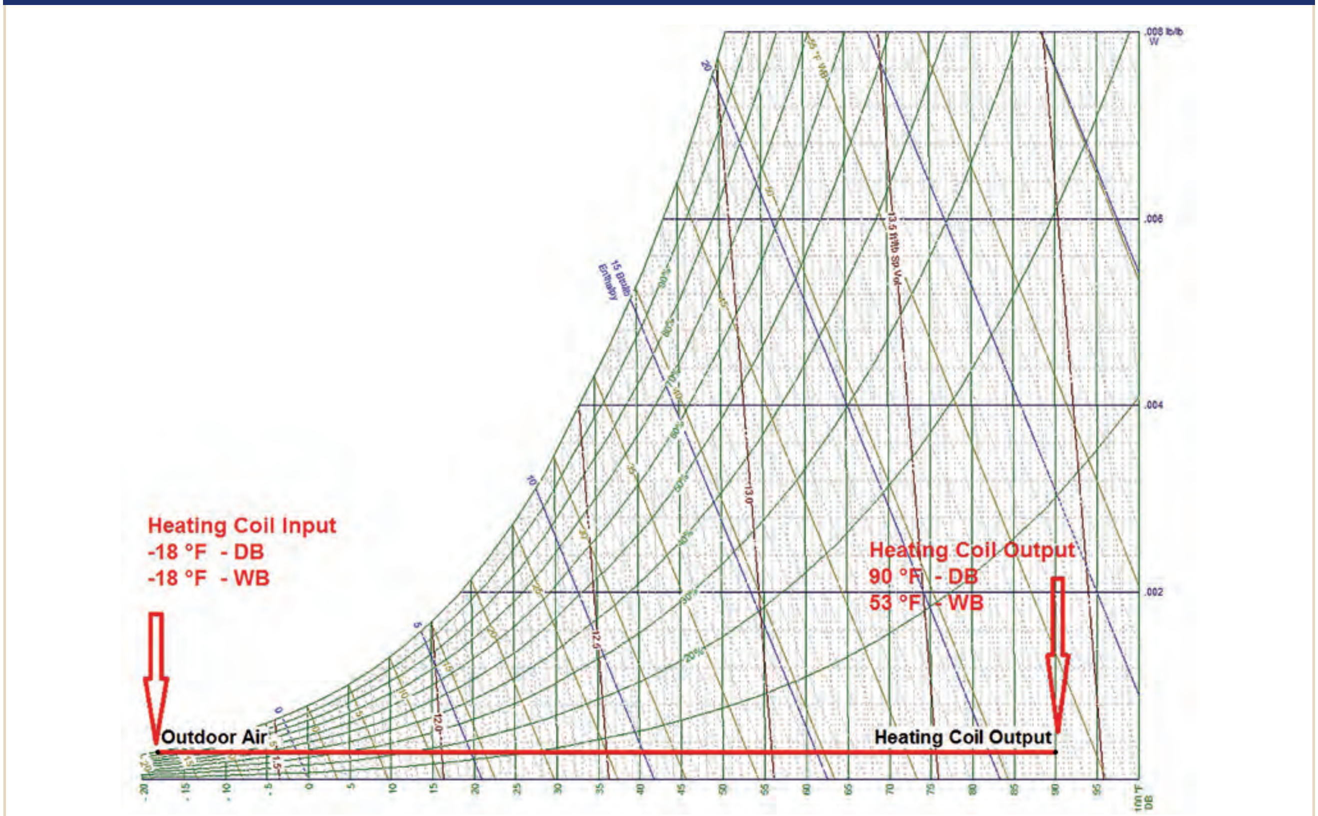
FIGURE 1 Air heating process.



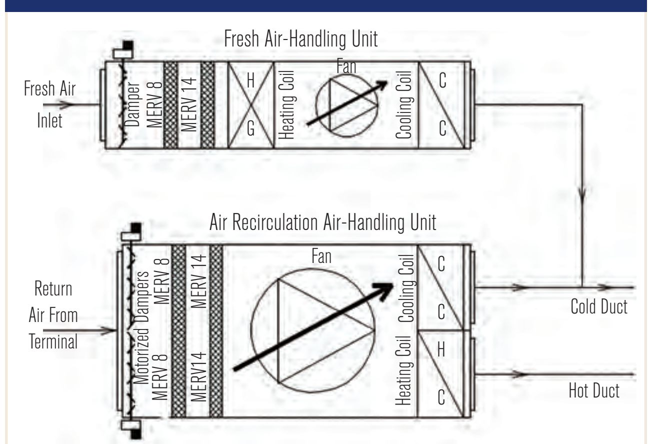
existing, almost fully packed mechanical room where the fresh air-handling unit is installed. Increasing the size of the existing mechanical room went beyond the project's budget. For that reason, Alternative 2 was discarded. Alternative 1 was discarded because it was the least energy efficient among the three alternatives.

How Does A Living Wall Work?

Based on Alternative 3, the engineering and architecture team launched a pilot project for building a living wall in one of the terminal commercial zones. The living wall's face area is 240 ft^2 (22.3 m^2). Airflow by unit area of living wall is 20 cfm/ft^2 (0.1016 m/s), as recommended by the wall's manufacturer.[2] As shown in *Figures 3* and *4* and because the living wall's plenum is connected to the air-handling unit's return duct, the negative pressure inside the wall's aluminum air plenum forces the air surrounding the wall to pass through the following consecutive layers:

- **Plants** act as a biofilter and oxygen generator (the effect of air biofiltration and oxygen addition on the indoor air quality is an added value, but is beyond the scope of this article).[3]

FIGURE 2 HVAC system configuration



- **Wet synthetic growth material** where air is humidified by a continuous water flow from top to bottom. Water (minus the portion absorbed by air flowing through the living wall) is recuperated in the catch basin and recirculated thorough the living wall (pumped up to the top of the wall).
- **Aluminum air plenum holes** where humidified air is channeled to the air-handling unit return air duct.

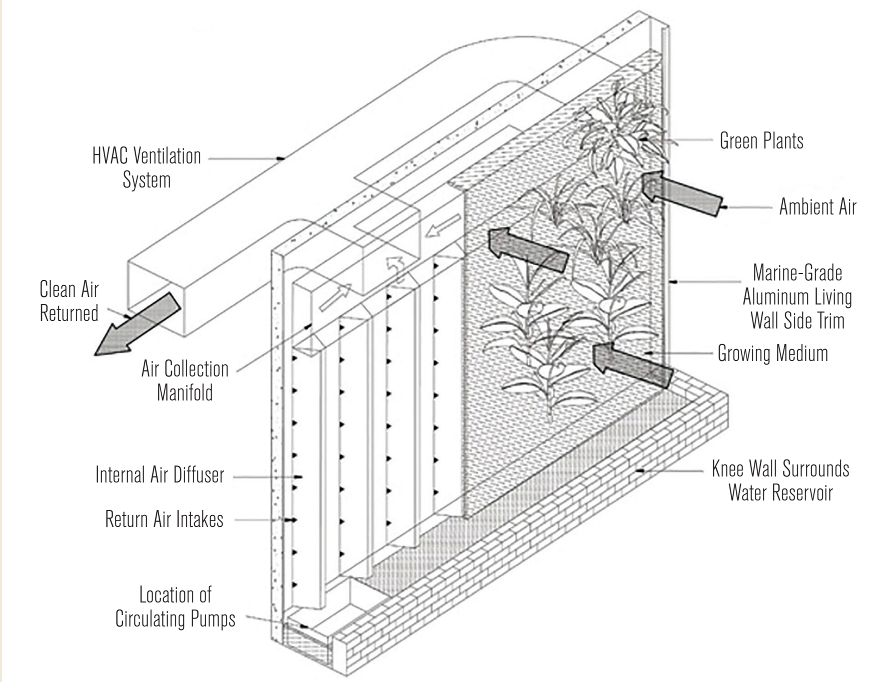
The configuration of the dual duct air-handling system at the end of the living wall project will look as shown in *Figure 5*.

Living Wall Humidification Capacity

Total airflow through the living wall = 20 cfm/ft^2 × 240 ft^2 = 4,800 cfm (2.267 m^3/s). The terminal air temperature in winter is maintained at 70°F (21°C). For this calculation, we will consider the lowest measured relative humidity of 12%.

The quantification of water vapor added to the air mass is the result of studies conducted by the living wall manufacturer and the University of Guelph.[2] Here are the mathematical models.

FIGURE 3 Living Wall.



1. Water vapor added (lb$_w$ per ft^3 of air treated) = $0.000336764\,x^{(-0.32)}$ [(g$_w$ per m^3 of air treated) = $0.995\,x^{(-0.32)}$].

2. Water vapor added (lb$_w$/h per ft^2 of biofilter) = $0.0055\,x + 0.041$ [(g$_w$/h per m^2 of biofilter) = $5{,}300\,x + 200$].

Where:

- x is the flux of air through the biofilter (cfm [m^3/s] of air treated per ft^2 [m^2] biofilter) (between 0.067 ft/s and 0.66 ft/s [0.02 m/s and 0.2 m/s]);
- w is water vapor; and
- g$_w$ is gram of water vapor.

At the entrance of the living wall, the absolute humidity is 0.0019 lb$_w$/lb$_a$ (1.9 g$_w$/kg$_a$), the enthalpy is 18.9 Btu/lb$_a$ (44 kJ/kg$_a$), and the specific volume is 13.392 ft^3/lb$_a$ (0.836 m^3/kg$_a$). (*a* is dry air, and lb$_a$ is pound of dry air.)

FIGURE 4 Living Wall principle of operation.

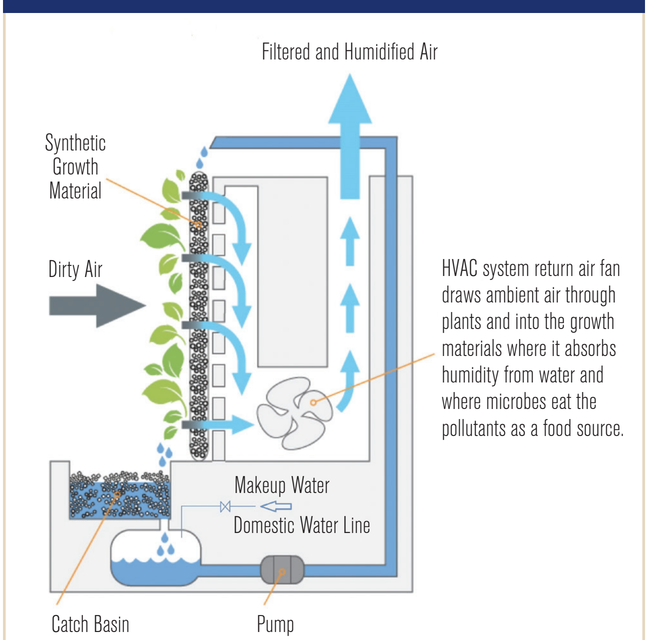
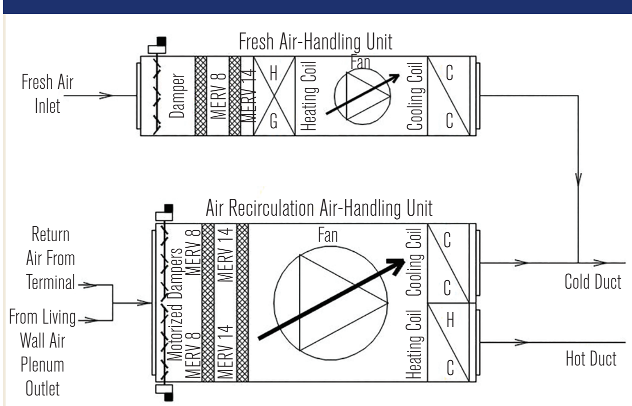


FIGURE 5 Finished configuration of dual duct air-handling system.



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The flux of air through the biofilter $x = 3.5844$ ft^3/s air treated per ft^2 (0.1015 m^3/s air treated per m^2).

The water vapor added = 0.00012924 lb$_w$/ft^3 (2.0686559 g$_w$/m^3) of air treated.

The water vapor addition mass flow rate = 0.1512 lb$_w$/h per ft^2 (738.2 g$_w$/h per m^2) of biofilter.

The absolute humidity at the living wall exit is 0.0019 lb$_w$/lb$_a$ + 0.00012924 lb$_w$/ft^3 × 13.392 ft^3/lb$_a$ = 0.0036308 lb$_w$/lb$_a$ (3.6308 g/kg).

Since the process through the living wall is evaporative humidification, the enthalpy at the living wall's inlet is the same as the one at its exit (18.9 Btu/lb$_a$ [44 kJ/kg$_a$]).

Placing the living wall's calculated absolute humidity and enthalpy on a psychrometric chart (*Figure 6*), we can easily conclude the remaining air properties:

- Relative humidity of 30.7% (an increase of 18.7% from 12%); and
- A dry-bulb temperature of 62.1°F (16.7°C), a decrease of 7.9°F (4.4°C) from 70°F (21°C).

The sequence of operation of the recirculating air-handling unit has been modified:

- For winter operating mode, supply air temperatures of the recirculating AHU's cooling coils have been limited to dry cooling (up to a maximum of 85% relative humidity). This is to avoid

FIGURE 6 Air humidification process through Living Wall.

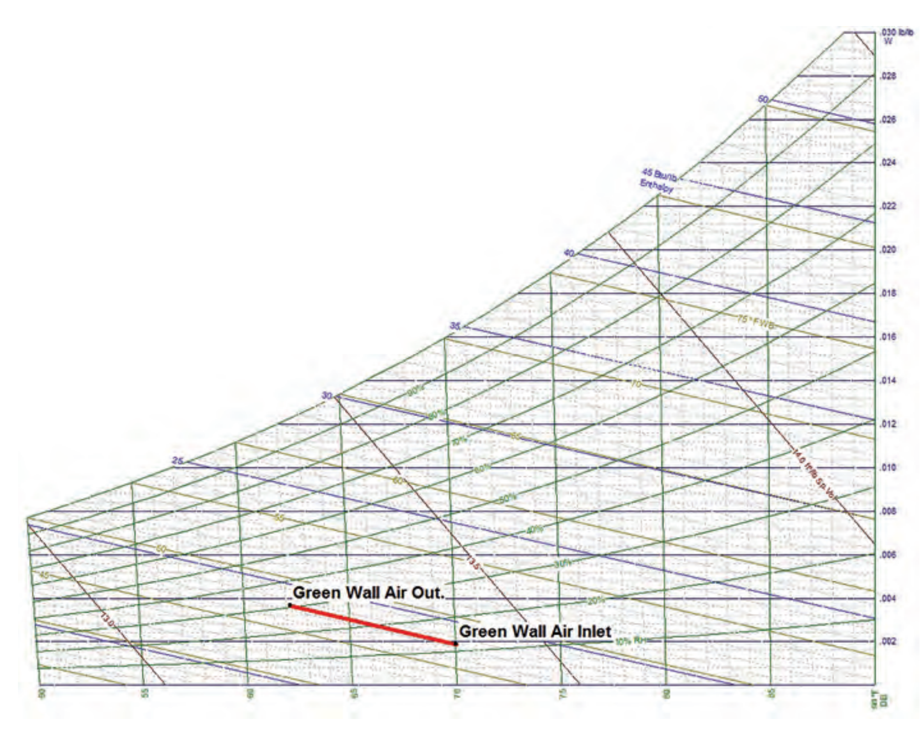
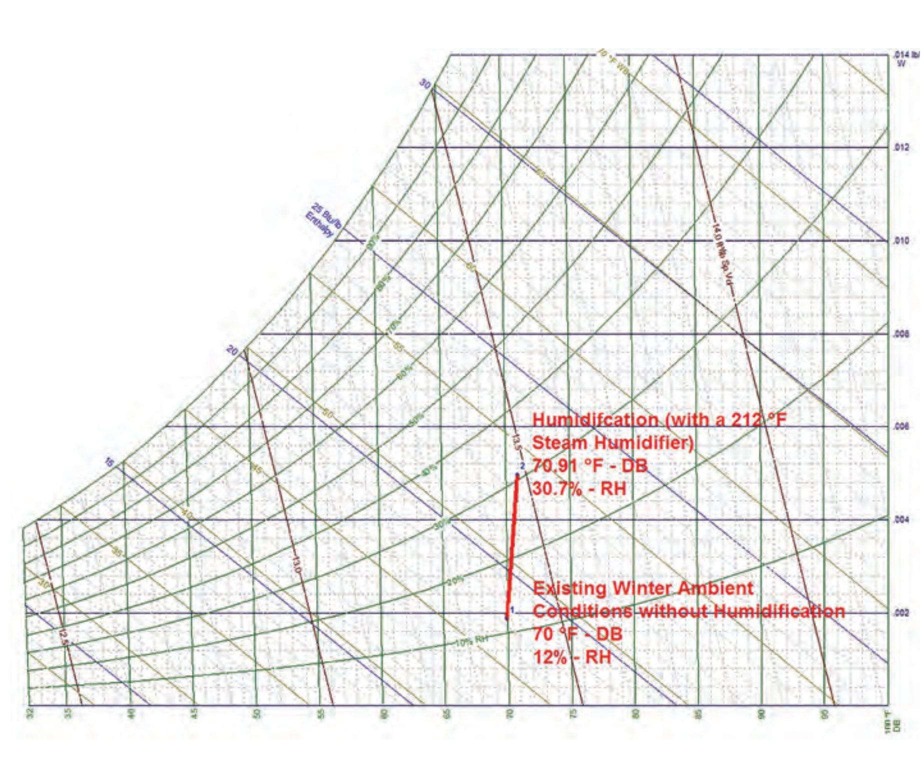


FIGURE 7 Air humidification process through steam humidifier.



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condensing the water vapor when humidified air is passing through the cooling coil.

- The living wall is equipped with a motorized volume damper at the plenum outlet for space humidity control. The motorized damper is opened by the terminal building management system (BMS) when measured space relative humidity is below its setpoint. The BMS closes the same motorized damper when space relative humidity is above or equal to its setpoint.

Alternative 3 Versus Alternative 1

The 7.9°F (4.4°C) decrease in return air temperature while passing through the living wall adds 12 kW to the recirculating air-handling unit heating coil: 1.08 Btu/h × 4,800 cfm × 7.9°F = 40,953.6 Btu/h (12 002.3 W) or 12 kW.

The heating load required to humidify 4,800 cfm (2.267 m^3/s) of outdoor air at 70°F (21°C) dry-bulb temperature and 12% relative humidity to 30.7% relative humidity with a 212°F (100°C) steam humidifier = (4,800 cfm/13.43 lb_a/ft^3) × (22.44 Btu/lb_a–18.9 Btu/lb_a) × 60 min/h = 75,913 Btu/h (20 068 W) or 22.25 kW (see *Figure 7*).

Total savings = 22.2 kW–12 kW = 10.25 kW.

Conclusion

In a retrofit context in an extremely cold climate (existing building with very limited space and where the existing air-handling units didn't reach the end of their expected lifetime), evaporative humidification and botanical air filtration by the means of living walls is one of the most economical and sustainable options.

Beside the economical and energy-efficiency benefits, a living wall adds value to the space where it's located and increases the quality of life for passengers and employees.

References

1. Government of Quebec. 2017. "Regulation Respecting Occupational Health And Safety," Chap. S-2.1, r. 13. http://tinyurl.com/jhmd6nb.

2. Darlington, A. "Humidity and the Nedlaw Indoor Air Biofilter.

3. Zhang, J. et al. 2010. "Botanical air filtration: myths and facts," *ASHRAE Journal* 52(12). ■