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Improving automation routines for automatic heating load detection in buildings

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Abstract

Energy managers use weather compensation data and heating system cut off routines to reduce heating energy consumption in buildings and improve user comfort. These routines are traditionally based on the calculation of an estimated building load that is inferred from the external dry bulb temperature at any point in time. While this method does reduce heating energy consumption and accidental overheating, it can be inaccurate under some weather conditions and therefore has limited effectiveness. There remains considerable scope to improve on the accuracy and relevance of the traditional method by expanding the calculations used to include a larger range of environmental metrics.

It is proposed that weather compensation and automatic shut off routines that are commonly used could be improved notably with little additional cost by the inclusion of additional weather metrics. This paper examines the theoretical relationship between various external metrics and building heating loads. Results of the application of an advanced routine to a recently constructed building are examined, and estimates are made of the potential savings that can be achieved through the use of the routines proposed.

Key Words:

Weather compensation, building control, heating system optimization, building heating loads.

1. Introduction

This paper will evaluate the benefits of extending the number of metrics used in weather compensation and building heating load detection routines from the traditional use of a single external dry bulb temperature, to a more comprehensive consideration of solar radiation, wind speed and dry bulb temperature. It is investigated whether this approach will produce significantly more accurate results due to the larger range of external environmental metrics used. This paper will also examine possible methods of calculating an inferred building heat load based on these parameters, in a form that can easily be incorporated within a real-time BMS algorithm.

Initially a simplified formula was developed and implemented in a building control system to allow the study of the concept, its benefits, and any potential effects on occupant comfort.

Within the test building a simple weather station was installed and connected to a building management system.

For the test project, a simplified formula for determining the building load was derived, by developing and generating an equivalent external temperature that was based on the calculation of wind chill on a human body, adjusted to include solar radiation influence.

Human wind chill is not a control method, nor is it ideal for a building application, but it provided a rough system that could be implemented within a short time period within the test building, and later enhanced. The following formula was the basis of the initial control routine:

$$T_{wc} = 13.12 + 0.6215T_a - 11.37V^{0.16} + 0.3965T_aV^{0.16}$$

T_{wc} = Effective wind temperature (˚c) T_a = Air temperature (˚c)
V = Win velocity (km/hr) *(Wind Chill Method, Siple and Passel). (2010).*

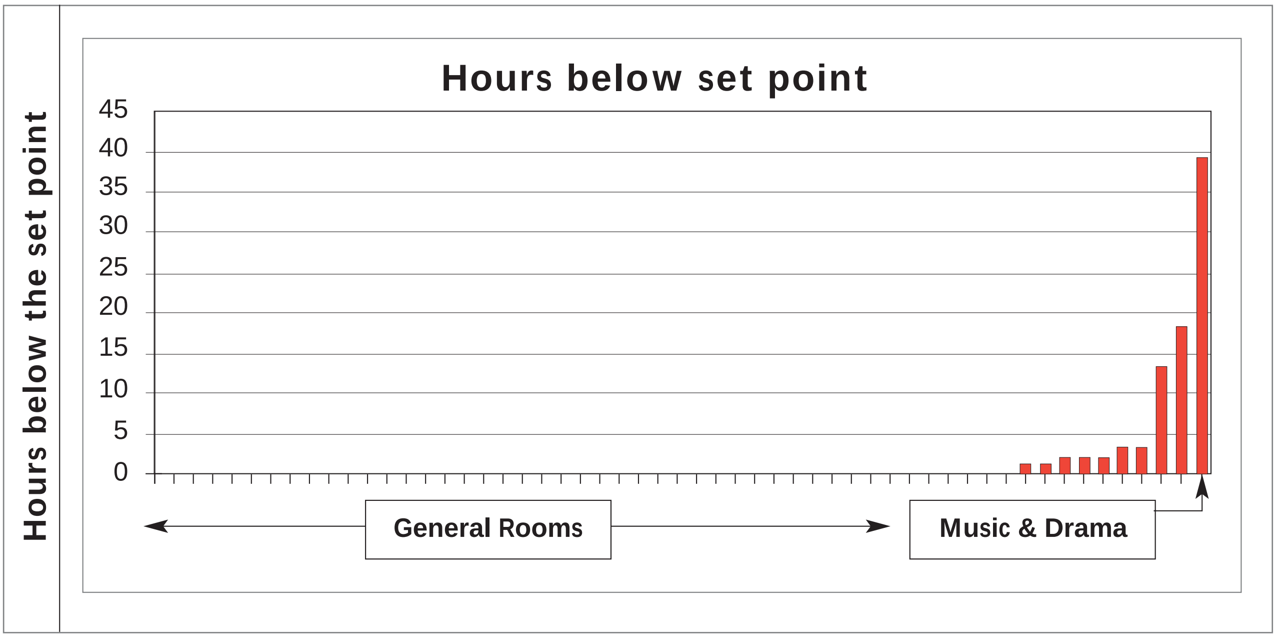
2. The case study

The results from the test building were encouraging and prompted the consideration of more advanced models.

The detailed analysis provided us with significant insight to building performance and how it is linked to its design.

Graph 1 shows the amount of time that each room within the test building is below its set point temperature. This in turn, on comparison, gives an indication of the additional heat loss for each of the problem rooms. It was observed that the governing equations were only as good as the worst case room which stresses that the identification of the worst case rooms and their improvement can lead to significant energy savings as the entire building heating system cannot be turned off (or fully tuned through compensation) until the worst case room is satisfied.

Some useful conclusions were drawn from this data, which motivated us to continue further research:



Graph 1. Hours which the test rooms fell below their set point.

- For most rooms the enhanced weather compensation and auto-off routines are working extremely well;
- There will always be some rooms that fall below their temperature set point because users leave windows open etc;
- One room was cold for a good reason – it was losing considerable amounts of heat to an adjacent room that was held at a lower set point temperature;
- The worst case rooms contained large amounts of glazing and over-sized roof lights. Some roof light commissioning errors were also detected in these rooms as a result of monitoring.

The overall system performance could have been improved by concentrating on reducing the heat loss from these worst-case rooms at design stage.

3. Research questions

The individual principles of this research have been well examined by previous researchers, but the combination of these principles has not yet been examined. The following research questions were posed to form the basis of this research:

1. Why do the traditional methods of compensation not produce optimal results?
2. How can a formula be developed that can combine the various weather variables to produce a readily-usable improvement to building load inference?
3. Can the formula be optimised and tuned for a particular building's geometry and construction?
4. How can infiltration and the effects of wind on surface resistances be modelled accurately?

4. Buildings and current methods of weather compensation and auto off

Weather compensating control is designed to run the boiler at a lower temperature based on the actual load required. The controller saves energy in a number of ways.

- It automatically turns off the heating circuits if the outside temperature rises above a pre-set limit;
- It automatically adjusts the flow and return temperature to the boiler so that the boiler supplies the correct amount of heat based on the outside and measured room temperatures. This is particularly beneficial when used in conjunction with a condensing boiler;
- It avoids temperature swings within the room, leading to greater comfort at lower temperatures;
- It eliminates the problem of short cycling (short run times and short off times);
- It reduces losses when users accidentally leave windows open;
- It reduces standing losses from heat-producing appliances and distribution systems.

The standard model for weather compensation is based purely upon a simplified algebraic relationship to the changing external outdoor temperature and a predetermined on/off set point.

Its purpose is to vary the flow temperature and therefore the output of heat emitters to match the load required to either heat up a space or maintain its temperature at its set point.

This is achieved mathematically with the aid of an external temperature sensor and BMS by equating a necessary equivalent flow temperature for the system and mixing the boiler flow water with return water from the emitter circuit to achieve this reduced flow temperature.

Simple algebraic approximations to produce numerical solutions for weather compensation were determined based on the principles that:

- The functions of the equation had to be representative of the building by using particular constants;
- The functions had to be as simple as possible so that they could be developed into a standard module and used with BMS systems easily;
- The functions had to be such that they protect against unstable solutions for specific cases.

The principle of coupling weather compensation with water temperature is based on an energy balance of the heating system:

$$m \times C_p \times (\theta_F - \theta_R) = K \times A_F \times (\theta_M - \theta_{ai})^n = U \times (\theta_{ai} - \theta_{ao})$$

m = mass flow rate of water; C_p = specific heat capacity of water;
$K \times A_f$ = emitter constant; U = heat loss coefficient;
θ_F = water flow temperature; θ_R =water return temperature;
θ_M = mean emitter water temperature; θ_{ai} = internal temperature;
θ_{ao} = external temperature.

The heat produced by the system is equal to the heat delivered to the space by the emitters, which is equal to the heat loss from, or absorption by, the space.

When each element is divided by its design condition, all design constants will cancel out and result in a set of temperature ratios:

$$\frac{(\theta_F - \theta_R)}{(\theta_F - \theta_R)_D} = \frac{(\theta_M - \theta_{ai})^n}{(\theta_M - \theta_{ai})_D^n} = \frac{(\theta_{ai} - \theta_{ao})}{(\theta_{ai} - \theta_{ao})_D}$$

To produce a realistic weather compensation equation this research must examine the heat loss based on external temperature, wind speed and solar radiation for a given building geometry. These individual sections will be dealt with at a later stage of the paper.

Our simplified heat loss formula can then be linked to a flow water temperature controlled by Iterative solver software to account for the dynamic nature of the changing heat load due to changing temperatures and weather variables.

In this approach the equation will be altered so that the net heat loss (Q_{net}) will substitute the existing heat loss component:

$$m \times C_p \times (\theta_F - \theta_R) = K \times A_F \times (\theta_M - \theta_{ai})^n = Q_{net}$$

$$\frac{(\theta_F - \theta_R)}{(\theta_F - \theta_R)_D} = \frac{(\theta_M - \theta_{ai})^n}{(\theta_M - \theta_{ai})_D^n} = \frac{Q_{net}}{Q_D}$$

Where Q_{net} is the heat loss from the measured weather data and Q_D is the system design capacity, i.e. the maximum amount of heat that the system is required to output during the day, not on building start up. This is as the building only requires a fraction of the heating load under normal conditions compared to the load required to bring a whole building up to temperature.

These temperature ratios may then be re-arranged to form a set of equations that together define the required flow temperature to achieve the heating load necessary to offset heat loss.

Equation 1: The required mean emitter temperature θm

$$\frac{(\theta_M - \theta_{ai})^n}{(\theta_M - \theta_{ai})_D^n} = \frac{Q_{net}}{Q_{net\ D}}$$

Therefore the required mean emitter temperature θ_M is:

$$\left[(\theta_m - \theta_{ai})_D^n \times \frac{Q_{net}}{Q_{net\ D}}\right]^{\frac{1}{n}} + \theta_{ai}$$

Equation 2: The required flow and return difference (θ_F - θ_R):

$$\frac{(\theta_F - \theta_R)}{(\theta_F - \theta_R)_D} = \frac{Q_{net}}{Q_{net\ D}}$$

Therefore the required flow and return difference (θ_F - θ_R) is:

$$(\theta_F - \theta_R)_D \times \frac{Q_{net}}{Q_{net\ D}}$$

And using the equations (1) and (2) the resulting flow temperature is:

$$\theta_F = \frac{(\theta_F - \theta_R)}{2} + \theta_m$$

This produces the ideal flow water temperature for varying external temperatures. The existing method produces an algebraic model for external temperature which has been proven from analysis of ongoing data recording within several of the buildings that have been monitored by the author to be inaccurate, far too simple, and to produce flow temperatures that are far too high for the required loads. The traditional solution to this problem has been to increase weather compensation and auto/off routine set points to cover the worst case error in the formula. These result in significant unnecessary energy loss in scenarios where the error is large, most notably on cold days with large solar gains, which are particularly common in many cold countries.

Monitored results from the test building indicate a notable improvement in control by the use of the advanced temperature inference method; however it is appropriate to develop the formula further.

The equations governing the value of Q_{net} will now be discussed in relation to the previously-stated wind speed, solar radiation and external temperature. Each weather influence will be analysed from first principles, and formulated with the intention of removing the need for complex thermodynamic properties and generic empirical constant values from dated sources which are not specific to a particular situation.

The objective is to achieve environmental comfort without producing a flow temperature that is unnecessarily high or one that would lead to underachievement of the internal temperatures.

5. Wind influences on building energy consumption

5.1 General

Wind influences building energy consumption by affecting:

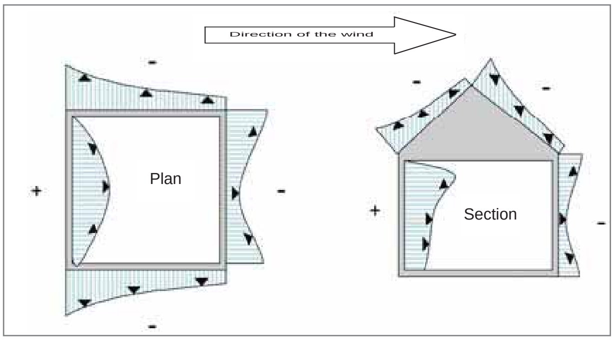


Fig. 1. Building Pressure Distribution.

- Air infiltration of conditioned spaces. Pressure gradients and hence mass transfer through the surfaces is altered by wind speed;
- The rate of heat transfer from external surfaces by altering the surface heat transfer coefficient.

Air movement is an important influence on energy loss. With increasingly improved insulation levels in buildings, the level of air permeability has become the predominant factor for loss of heat.

Wind effects the air pressure distribution across the building surfaces causing mass transfer through the apertures of the walls, windows, doors and roof. The pressure distribution depends on the velocity/pressure field around the entire building, Arens, et al (1981).

In brief, there is a pressure increase on the windward side of the building and a pressure decrease on the leeward sides where flow has accelerated (Figure 1).

5.2 Infiltration model discussion

The aim at this juncture is to come to an algebraic approximation of the numerical solution of the flow equations so that it may be applicable to a building under varying wind velocity so that the equivalent infiltrative loss may be determined.

Thus from known indoor and outdoor conditions and calculated values of ventilation and infiltration rates, one may calculate the increased heating loads on the building due to wind.

Heat loss by infiltration is directly proportional to the amount of flow through surface openings, proven in the experimental tracer gas measurements in closed residences Dick (1949) and Ross et al (1980). To solve the flow equation the relationship between flow and the wind velocity, or, between flow and the increased differential pressure caused by wind velocity on the structure is required.

The following simplifying assumptions were used in the development of the ventilation calculations:

- The building is a single, well mixed zone;
- Wall leaks are evenly distributed over four walls;
- The flows through all building leaks are characterised by the same power law exponent of pressure, n.

This model improves estimates of air infiltration rates by incorporating a power law pressure-flow relationship into the model from first principles:

$$Q = C\Delta P^{n}$$

Fan pressurisation tests performed by Beach (1979), Sulatisky (1984), as well as theoretical considerations from Walker, Wilson and Sherman (1996), have shown that the orifice flow assumption for the power constant '*n*' used in the many infiltration models is unrealistic, as it is usually assumed at 0.5, and that it is better to use an air tightness test determined orifice flow.

The parameter '*n*' is usually found from fan pressurisation tests of the building itself. For a typical residential building $n \approx 0.67$, about midway in its range from $n = 0.50$ for orifice flow to $n = 1.0$ for fully developed laminar flow.

The documented research of Akins et al (1979) found that the pressure coefficient for the four walls of a building could be simplified to an algebraic average of wall pressure coefficients and was sufficiently accurate to define pressures acting on the building as a whole so as heat loss calculations may be performed. Akins among others came to this conclusion through field research rather than theoretical calculations.

5.3 Infiltration model heat loss equation

For the equation the air permeability of the building is determined by air pressure testing @ 50 Pa.

This is representative of test conditions but may be used in determination of the air flow through the structure at any pressure difference.

Using the below equation based on the power law flow relationship, the volume flow of infiltration and exfiltration can be determined:

$$Q = C \times A \times \left[\frac{2\,\Delta P}{\rho}\right]^{0.5}$$

Where, Q = Volume flow rate (m^3/s); A = leakage area (m^2);
ΔP = differential pressure (Pa); C = discharge coefficient from testing' ρ = air density (kg/m^3); n = flow power factor from testing.

To determine the air leakage at a pressure difference other than that of the test value of 50Pa, the area of leakage is expressed as:

$$A = \frac{Q}{C \times \left[\frac{2\,\Delta P}{\rho}\right]^{n}}$$

The area of leakage will not change so therefore if A1 = A2,

$$\frac{Q_1}{C \times \left[\frac{2\,\Delta \boldsymbol{P_1}}{\rho}\right]^{n}} = \frac{Q_2}{C \times \left[\frac{2\,\Delta \boldsymbol{P_2}}{\rho}\right]^{n}}$$

and where,

- Q_1 and ΔP_1 correspond to the air flow and pressure at testing conditions;
- Q_2 and ΔP_2 correspond to the air flow that must be determined at the actual pressure differential occurring due to wind.

As the air flow is required at the actual pressure differential that is occurring, then this equation can be rearranged to yield:

$$Q_2 = \frac{Q_1 \times C \times \left[\frac{2\,\Delta \boldsymbol{P_2}}{\rho}\right]^{n}}{C \times \left[\frac{2\,\Delta \boldsymbol{P_1}}{\rho}\right]^{n}}$$

With further arrangement of the equation a much more simplified form results where the common constants of the discharge coefficient (C) and air density (ρ) are eliminated:

$$Q_2^{\frac{1}{n}} = \frac{Q_1^{\frac{1}{n}} \times C \times \frac{2\,\Delta \boldsymbol{P}_2}{\rho}}{C \times \frac{2\,\Delta \boldsymbol{P}_1}{\rho}}$$

$$Q_2^{\frac{1}{n}} = Q_1^{\frac{1}{n}} \times \frac{2\,\Delta \boldsymbol{P}_2}{\rho} \times \frac{\rho}{2\,\Delta \boldsymbol{P}_1}$$

Leaving the simplified equation:

$$Q_2^{\frac{1}{n}} = Q_1^{\frac{1}{n}} \times \frac{\boldsymbol{\Delta P2}}{\boldsymbol{\Delta P1}}$$

And finally removing the common power applied to the flow rates:

$$Q_2 = Q_1 \times \left[\frac{\Delta \boldsymbol{P}_2(\boldsymbol{actual})}{\Delta \boldsymbol{P}_1(\boldsymbol{tested})}\right]^n$$

The final equation gives the actual infiltration rate Q_2 or Q_v (m^3/s) from a relationship between the achieved air tightness of the building at its differential pressure at the time of testing, against the current pressure due to wind velocity on the building (i.e. the actual pressure).

It is worth mentioning for the calculation, that the air infiltration (m^3/s) at testing or otherwise may be calculated with the equation:

$$Q_1 = \frac{A \times AP}{3600}$$

Where, AP = air permeability ($m^3/m^2/hour$); A = Building Envelope Area (m^2)

Geurts, C. and Van Bentum, C (2007) wrote that measurements of pressures in full scale (as opposed to model scale) are based on the same principle as in a wind tunnel. Differential pressure transducers can be used to measure the difference between the pressure on the surface of the building and a reference pressure, in other words the internal pressure of the building. The pressure transducer should be mounted flush on each facade.

An air pressure gauge capable of measuring very low air pressures and differential pressures is used on each façade to achieve an average pressure difference.

It is recognised that pressure transducers are not commonly used in building management systems and for practical reasons it may be necessary to use wind speed to infer pressures, particularly where the system is used on smaller, simpler buildings. For this reason the following conversion is included:

Empirical determination of the actual ΔP due to wind speed:

CIBSE Guide A states that the average pressure acting on any point on the surface of a building can be represented by the following equation:

$$P_{av} = 0.5\,\rho\,C\,V_z^2$$

Where, P_{av} = average surface pressure due to wind (Pa); ρ = density of air (kg/m^3); C = empirical wind pressure coefficient for the building surface; V_z = mean wind velocity at the building height z (m).

$$V_z = (V_m)kz^a$$

Where, V_m = wind speed at 10m height; Z = building height (m); k and a = empirical terrain coefficients for wind speed.

To complete this equation it must be related to a quantity of heat loss, in our case watts (W):

$$q_v = c_p\,\rho\,Q_v\,(t_i - t_o)$$

Where, q_v = ventilation heat loss (W); c_p = specific heat capacity of air (J/kg K); ρ = density of air (kg/m^3); Q_v = air volume flow (m^3/s); t_i = inside air temperature (°C); t_o = outside air temperature (°C).

As the change in the density of air and the specific heat capacity over the expected temperature difference is negligible, the figures for specific heat capacity and density can be taken approximately as 1005 J/kg K and 1.29 kg/m^3.

This equation becomes:

$$q_v = 1296\,Q_v\,(t_i - t_o)$$

Q_v or (Q_2) was previously determined to be:

$$Q_2 = Q_1 \times \left[\frac{\Delta \boldsymbol{P}_2(\boldsymbol{actual})}{\Delta \boldsymbol{P}_1(\boldsymbol{tested})}\right]^n$$

The final expression for ventilation loss due to wind becomes:

$$q_v = 1296 \times Q_1 \times (\Delta T) \times \left[\frac{\Delta \boldsymbol{P}_2(\boldsymbol{actual})}{\Delta \boldsymbol{P}_1(\boldsymbol{tested})}\right]^n$$

5.4 Reduced external resistance due to greater wind velocity

Wind can have a significant effect on surface heat transmission. The total U value (U_T) of the glazed construction is dependent on the windows physical properties as well as the wind condition which has an effect on the external surface resistance of the window. Wind flow around a building causes turbulent forced convection heat transfer from the building envelope leading to higher energy consumption. The wind affects the external resistances of the building and therefore the U value will vary with the wind velocity.

This has been proven to be significant for poorly insulated materials, such as glazing Sturrock (1971). The resistance of say blockwork or masonry is much greater than that of glass and therefore the variation due to increased wind velocity is negligible in the case of the structure.

The increase in the heat transfer coefficient has been mathematically modeled by several researchers, both theoretically and through field investigation and testing of buildings. Forced convection (wind) dominates the exterior film coefficient. This film coefficient is a function of wind speed (v in m/s) and the direction of the wind. The correlations by Ito and Kimura (1972) among other researchers concluded with equations to express the surface resistance but many became unreliable at very low wind speeds and even more so in conditions without wind.

Existing research papers seem to leave some questions unanswered, and this author believes that the difficulty in determining such an equation comes from the many existing variables. Most notable of these obstacles are:

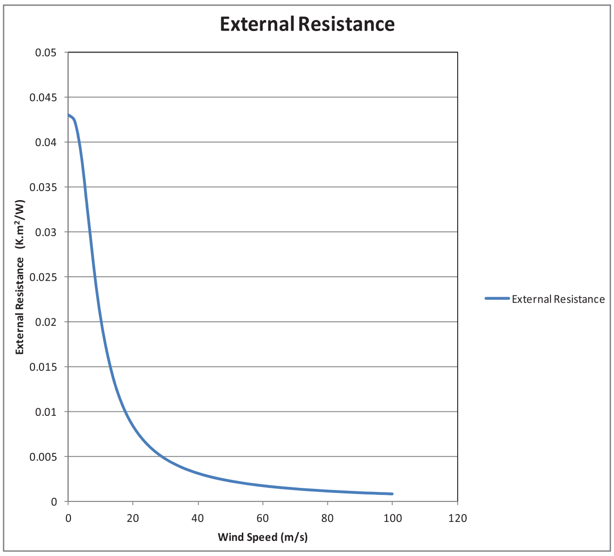
- The unknown transition region between natural and forced convection is poorly understood;
- There is no theoretical basis for their combination beyond the expectation that the film coefficient should vary continuously between the two regions.

The model which has been chosen here is the “MoWitt” model Yazdanian et al (1994), whereby their research shaped an equation for the determination of the exterior convective coefficient for low rise buildings.

$$h_{co} = \sqrt{[\,C_t(\Delta T)^{1/3}\,]^2 + [\,aV^b\,]^2}$$

A simple model, similar to the MoWitt, was produced for the calculation to include both natural and forced convection. The model does not distinguish between windward or leeward, similar to many previous models, but differentiates itself in that:

- At 0-2 m/s wind speed the “MoWitt” model is the same for windward and leeward data unlike for instance the ASHRAE model;
- The values of the constants are field measured and determined by standard statistical techniques.



The results have been recorded to be very accurate, with constant values and deviations of:

	C_T (W/m^2.K$^{4/3}$)	a	b
Windward	0.84 ± 0.015	2.38 ± 0.036	0.89 ± 0.009
Leeward	0.84	2.86 ± 0.098	0.617 ± 0.017
Assumed values	0.84	2.62	0.7

For the purposes of simplifying the equation a weighted average value between the windward and leeward will be assumed, Previous research has proven this to be sufficiently accurate for the calculation procedure. Note that the external resistance of the model at 2m/s is roughly that indicated by CIBSE Guide A, to be 0.04m^{2}K/W.

The range of resistance values simply due to forced convection is large as can be seen. Wind speed records from Met Eireann indicate that wind speed is usually on average only 5 m/s but can reach up to 58 m/s. This puts into context the broad range over which the surface resistance can alter.

The final equation for the window external resistance by laws of indices becomes:

$$ho = \sqrt{([0.84(\Delta T)^{7/3}] + [2.62(V)^{2.7}])}$$

6. Influence of solar radiation on the heating load

6.1 General

Any glazed (or transparent) opening in a building, such as glass doors, windows, skylights, because of their transparency, transmits solar radiation into the building.

When solar radiation takes effect on a building wall a part of it is absorbed, while the remaining part is reflected back. Only a small fraction of the radiation is absorbed at one time by structure into the interiors of the building due to the thermal resistance of the materials.

However, in the case of transparent surfaces, a major portion of the solar radiation is transmitted directly to the interiors of the building instantly.

Thus the glazed surfaces contribute a major part of heating load contribution of a building. The energy transfer due to glazed surfaces depends on the characteristics of the surface and the solar radiation conditions.

6.2 Solar gain equation

- The SHGF is the heat flux due to solar radiation through the reference glass (SS);
- A Shading Coefficient (SC) may also be defined such that the heat transfer due to solar radiation is given by:

$$q_s = SHGC \times A_p \times E_D \times SC$$

Where, q_s = instantaneous energy flow (W); U_T = overall coefficient of heat transfer (W/m^2-K); T_{in} = interior air temp (K); T_{out} = exterior air temp (K); A_p = total projected area of gain through glazing (m^2); SHGC = overall solar heat gain coefficient (unitless); E_t = incident diffuse irradiance (W/m^2-K).

The SHGC is the fraction of the measured heat from the sun that enters through a window. SHGC is expressed as a number between 0 and 1. The lower a window's SHGC, the less solar heat it transmits. This may be obtained from the glazing manufacturer.

7. Combined weather compensating equations

This research paper has identified and developed the most appropriate equations into a form that could easily be used to develop an improved BMS control module for enhanced weather compensation auto/off routines. The final equations are as follows.

Heat loss by conduction through structural fabric (w)

$$q_w = U_{wall} \times A_{wall} \times (\Delta T)$$

Heat loss by conduction through glazing (w)

$$q_g = U_g^* \times A_g \times (\Delta T)$$

Where Ug* refers to the U value of glazing subject to its altered external heat transfer coefficient:

$$ho = \sqrt{([0.84(\Delta T)^{7/3}] + [2.62(V)^{2.7}])}$$

Wind driven Infiltration heat loss (w)

$$q_v = 1296 \times Q_1 \times (\Delta T) \times \left[\frac{\Delta \boldsymbol{P}_2(\boldsymbol{actual})}{\Delta \boldsymbol{P}_1(\boldsymbol{tested})}\right]^n$$

Solar gain through glazed surfaces (w)

$$q_s = SHGC \times A_p \times E_D \times SC$$

Net heat loss (w)

$$q_{net} = q_w + q_g + q_v - q_s$$

This may then be used to determine;

The required mean emitter temperature (θm)

$$\left[(\theta_m - \theta_{ai})_D^n \times \frac{Q_{net}}{Q_{net\ D}}\right]^{\frac{1}{n}} + \theta_{ai}$$

The required flow and return difference (θF - θR):

$$(\theta_F - \theta_R)_D \times \frac{Q_{net}}{Q_{net\ D}}$$

Resulting heating flow water temperature:

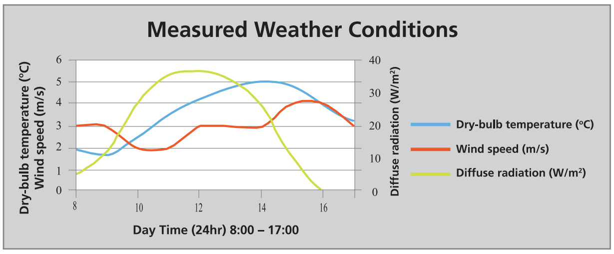
$$\theta_F = \frac{(\theta_F - \theta_R)}{2} + \theta_m$$

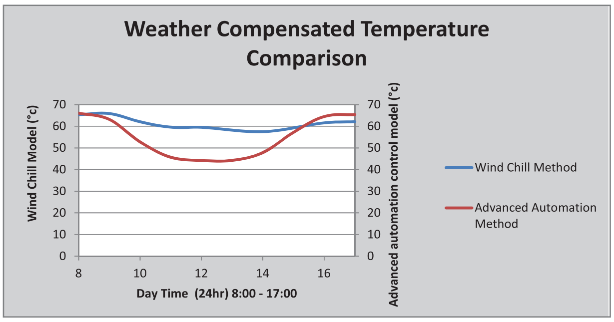
8. Case studies and findings

The following is a graphical representation of the comparison of compensated flow temperature models for the average hourly recorded weather variables of a mild day just before the test building's Christmas period.

The comparison is based on the predicted "Wind Chill Resultant Air Temperature Method" and recorded "Advanced Automation Method" for automatic heating load detection in buildings.

After the building's preheat period the building spaces are at their design internal temperature. The flow temperature is now subject to the heating load (kW) determined by the chosen weather compensation model to maintain this condition. If the weather conditions versus the compensated temperatures are examined in both cases, significant conclusions can be determined based on the deviations of both models.





Time lapse analysis of results

08:00

- The flow water temperature started at approximately the same reading for both methods (ΔT ≈ 1°c);
- The diffuse solar gain is low and has little effect on heat gains to the building;
- Wind speed too is relatively low at 2m/s;
- The building heat loss is therefore characterised by the difference between the internal and external air temperature readings.

11:00

- There are much larger differences in flow temperature (ΔT ≈ 14°c);
- The weather readings indicate lower recorded levels of wind speed, slightly higher external temperatures and solar levels 4-5 times greater than recorded at building start up;
- This causes a slight dip but essentially the same flow water temperatures for the wind chill model;
- The Advanced Automation Model relates the heat loss to Infiltration levels caused by wind pressure, and the difference between the internal air temperature and the external air temperature entering the room;
- At low wind speed (2 m/s) there is insufficient driving pressure force to cause heat loss as this construction has exceptionally low levels of air permeability;
- The flow temperature is compensated for by the much higher recorded levels of solar diffusion heat gain at this point of the day;
- Flow water temperatures are as a result ≈ 23% lower than required by the wind chill method but still sustained the internal air temperature;
- This pattern continued for the most part of the day.

16:00

- Low levels of difference in flow temperature (ΔT ≈ 3°c) can be observed;

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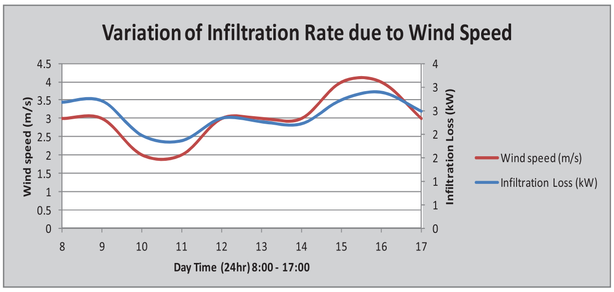
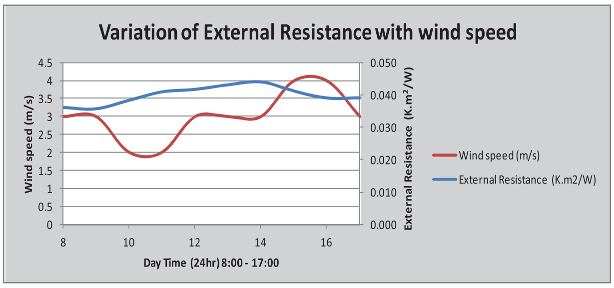
DOI: https://doi.org/10.21427/D7Q15Z

- The diffuse solar gain is low and has little effect on heat gains to the building;

- Wind speed was recorded to have increased above 4m/s causing increased heat loss by reducing the external resistance of the glazing, and also increasing the wind pressure.





- The building heat loss is therefore characterised by both the difference between the internal and external air temperature readings, and the increased infiltration loss from the building due to a greater wind pressure;

- Hence the flow water temperature is greater in the case of the advanced automation model.

9. Conclusions

The measured heating loads and recorded internal temperatures of the spaces were used to test the equation's predictions. By comparing the performance of this calculation to measured data the following observations can be made:

- The human wind chill calculation which was initially used to compensate for the effect of wind speed on temperature proved to have insufficient accuracy, demanding greater or lower levels of heating than required as the full extent of external variables were not used;

- Typical differences between measured heating and actual building demand were significantly improved by the inclusion of all weather parameters measured on site. Determining the full benefits of such an approach will require a full year's monitored analysis to examine all forms of weather extremes;

- The additional benefit of using the advanced automation model is that there will no doubt be reduced hunting (on/off) of the boiler and standing losses from the boiler and heating system can be greatly reduced. For example, in the case of the recorded data the difference in heat loss of insulated heating pipework at the respective mean water temperature for both compensation methods (55°c and 40°c) is 0.2 W/m.K and 0.14 W/m.K.

  In other words ≈ 30% less heat loss from the distribution flow and return pipes. Boiler standing losses account for 1.5-2% of the overall heating demand which can be directly linked to the water temperature. However, this loss can also be significantly reduced by turning boilers off once a no-load condition is detected. This no-load condition can be directly measured but such a direct measurement is problematic because users often accidentally leave windows open (or increase set points considerably higher than required) resulting in measured loads when there is no need to supply heat to the building. From observation, direct measurement can accidentally result in a considerably increased amount of time when the boilers are on but are not required;

- Disabling weather compensation during start up minimises the time that the boiler is on by maximising its output;;

  This has been shown to offer significant savings in the buildings monitored but has been recorded to overshoot the room set point in the mornings by 1°C, resulting in unnecessary heat losses;

- Outside of this research paper's discussion the author has noted that applying weather compensation reduces this overshoot but at the expense of increased energy. A simple routine has been applied to the test building that reduces the room set point temperatures during start-up and this has been monitored to produce excellent results as heat gains from occupants are significant on first entry to a room (due to the CO^2 reservoir within the room not requiring ventilation).

- A static offset has been used within the test room. However, the advanced compensator system proposed in this paper could be used to generate a dynamic offset, possibly resulting in further accuracies;

- The system detailed in this paper is based on hourly average weather variables, but a building's dynamic demand is strictly affected by its cumulative historic load. A full dynamic simulation could be run in real-time within the BMS, to produce an optimum indication of building load; however the complexities of a full dynamic simulation can be avoided by the use of a 4-hour cumulative gain calculation. This further potential enhancement to the method proposed is a real possibility that could easily be applied within existing BMS systems following further development.

10. Further research

It is the author's intention to apply the enhanced methods described to a real building to demonstrate the practicality of its application. A controls specialist will also be sought to implement the formula in the form of a control block that can easily be applied to any building.

A formula "tuner" can be developed to allow the formula constants to easily be tuned to a particular building and some initial work has been carried out on the methods applicable.

The proposal for the conversion of the formula to a dynamic 4-hour cumulative model can be easily developed and it is hoped that this method will be developed before the system is implemented within the next test building. The limitation of this dynamic method is the abilities of the controls hardware available to implement the dynamic method and direct discussion with the controls suppliers is required.

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