1. INTRODUCTION

Thermal bridging, or cold tracking as it is often referred, is a term that describes the unwanted ability of a component to transfer thermal energy from one side to the other. Strictly speaking, this property is not simply an opposite term to insulation. The "unwanted" nature of the term differs itself from terms like conductivity. More importantly this unwanted property normally has to be dealt with at the component level and cannot be averaged throughout the unit.

There are two principle issues to consider when designing the insulation of an air handling unit: (1) overall thermal efficiency of the structure and (2) thermal bridging properties of each component. The former is an averaged effect of insulation throughout the unit while the latter is related to each component of the structure. Note that the thermal bridging property should not be averaged. For example if we drive a screw through a well insulated air handling unit casing, the thermal efficiency may not be significantly affected as the sectional area of the screw is insignificant compared with the rest of the casing structure.

Conceptually, the thermal bridging effect, which would cause condensation on the surface and consequently corrosion of itself and adjacent components. Practically the test is whether condensation occurs on the surface of components or not. It is a simple yes/no question; to answer it we have to understand both the thermal property of each component and the requirement of this property against given ambient conditions.

The thermal property of a component can be improved if necessary by altering the design and/or material. When the thermal property meets the requirement, i.e. no condensation would occur, further improvement (which is usually expensive) is unnecessary. Clearly it requires a method of measurement of thermal bridging property of components. The measurement would then be examined against criteria to determine whether condensation would occur. This criterion is also a function of the ambient condition i.e. inside temperature, outside temperature and humidity of the air, which varies from place to place and time to time.

Clearly, in order to evaluate the thermal bridging property we need:

(1) a parameter that describes the thermal bridging (or anti-thermal-bridging) property of a component that can be easily determined either theoretically or experimentally;

(2) a method that interprets the parameter in terms of whether condensation would occur under given ambient conditions.

A thermal bridging factor k\textsubscript{b} has been introduced by the British standard (BS EN 1886:1998\textsuperscript{1}) which is the ratio of temperature difference between outside surface and inside air to that between outside air and inside air. The standard also introduced a testing method in determining k\textsubscript{b} and classification of the factor. The standard however restricts the test conditions, which makes it difficult to apply the method to cooling units. Also, the k\textsubscript{b} factor and its classification does not directly relate to the fundamental question - will condensation occur?

In this paper the suitability of the thermal bridging factor k\textsubscript{b} (BS EN 1886:1998\textsuperscript{1}) to the Australian applications has been examined. Our further development in adapting the concept and using it for predicting surface condensation is reported.

2. THE k\textsubscript{b} FACTOR

BS EN 1886:1998 is a standard that specifies mechanical performance of air handling units, including structural strength, thermal, leakage and acoustic performances. In this standard a thermal bridging factor k\textsubscript{b} has been defined as follows:

\[ k_b = \frac{\Delta t_e}{\Delta t_{av}} \]  

(1)

where

\[ \Delta t_{av} \] air-to-air temperature difference

\[ \Delta t_e \] the least temperature difference between mean internal air temperature and maximum external surface temperature (when internal temperature is higher)

\[ t_e \] mean external air temperature

\[ t_{av} \] mean internal air temperature

To determine the above, it is required by the standard to remove all mounted internal equipment such as fans and coils, increase the internal temperature and set the temperature difference 

\[ \Delta t_{D1} \] to 20-25k before the surface temperatures are measured.

The k\textsubscript{b} factor provides a description of thermal bridging property of air handling units, with which air handling units can be specified and compared in terms of thermal bridging property. The standard also gives a classification of the factor:

<table>
<thead>
<tr>
<th>Class</th>
<th>k\textsubscript{b}</th>
</tr>
</thead>
<tbody>
<tr>
<td>TB1</td>
<td>0.75 &lt; k\textsubscript{b} &lt; 1</td>
</tr>
<tr>
<td>TB2</td>
<td>0.6 &lt; k\textsubscript{b} &lt; 0.75</td>
</tr>
<tr>
<td>TB3</td>
<td>0.45 &lt; k\textsubscript{b} &lt; 0.6</td>
</tr>
<tr>
<td>TB4</td>
<td>0.3 &lt; k\textsubscript{b} &lt; 0.45</td>
</tr>
<tr>
<td>TB5</td>
<td>0 &lt; k\textsubscript{b} &lt; 0.3</td>
</tr>
</tbody>
</table>

There are however drawbacks to the specification:

(1) First the difficulty of applying the method due to restricted test conditions specified. e.g. it is not practical to determine the k\textsubscript{b} factor of an installed cooling unit.

(2) Second, the k\textsubscript{b} factor and its classification has not been directly related to predicting the surface condensation of a unit or its components.

3. THE COMPONENT APPROACH

Although the standard tends to use the k\textsubscript{b} factor as a descriptor to describe the overall property of a unit by using the least temperature difference (associated with the most thermal bridging component) in calculation, we found it is more convenient to establish kb for individual components, i.e.:

\[ k_b = \frac{t_e - t_{av}}{t_e} \]  

(2)

where

\[ t_e \] external surface temperature (°C) of the component concerned

\[ t_{av} \] mean external air temperature (°C)

Conceptually, the k\textsubscript{b} factor now is a property of a given component (not that of a unit). This (together with the thermal bridging chart introduced later) is useful for mapping out the thermal bridging property across the unit.

Consider the following model:

\[ R = R_{air-1} + R_{air-2} \]  

(3)

Considering the energy transferred through the layers (i.e. we have:

\[ \frac{1}{R_{air-1}} \frac{1}{R_{air-2}} = \frac{1}{R} \]  

(4)

The outside surface temperature can then be found by:

\[ t_0 = t_i - \frac{1}{R_{air-1}} \frac{1}{R_{air-2}} \]  

(5)

Substitute (5) into (2):

\[ k_b = \frac{t_e - t_{av}}{t_0} \]  

(6)

Equation (6) shows that the k\textsubscript{b} factor is a function of the thermal resistance of the component as well as that of inside and outside surface layer of air. If the inside and outside air are taken as constants (i.e. considering the inside air as moving within a specified speed range and outside air is close to still), the k\textsubscript{b} factor is then purely a property of the component.

Because the k\textsubscript{b} factor is independent of the temperatures, theoretically it can be measured regardless of the operating and ambient temperatures as long as there is a temperature difference (t\textsubscript{0}-t\textsubscript{i}). Equation (2). However, practically the accuracy of the measurement is affected by the temperature difference between inside and outside air.

This can be seen from Equation (2), i.e. for a given instrument accuracy

The thermal bridging factor of air handling unit components has been developed. A thermal bridging chart has been introduced by the British standard (BS EN 1886:1998\textsuperscript{1}) to the Australian applications. The kb factor now is a property of a given component (not that of a unit). This (together with the thermal bridging chart introduced later) is useful for mapping out the thermal bridging property across the unit.

ABSTRACT

Based on the thermal bridging factor k\textsubscript{b} introduced by BS EN 1886:1998\textsuperscript{1}, a method of determining and evaluating the thermal bridging property of air handling unit components has been developed. A thermal bridging chart has been designed on which the thermal bridging properties of components and the ambient conditions can be presented and compared to determine whether condensation would occur. The method introduced would give both manufacturers and users confidence in designing, specifying and evaluating air handling units in terms of surface condensation - one of the major concerns in the Australian application environment.
(e.g. ±0.2°C) the smaller the temperature difference the less accurate the \( k_b \) factor will be. In Australia, the temperature inside an air handling units is normally from 10 to 12°C and typical outside temperatures can be from 24 to 34°C, i.e. the difference can be 12 to 24K - a large portion of it is outside the 20K temperature difference specified by BS EN 1886:1998. If this 20K temperature difference can be reduced to 12K, it would mean that the \( k_b \) factor can be obtained easily on site for most of the units in Australia.

The following is a comparison of \( k_b \) accuracy when the inside and outside temperature difference is 12K and 20K, assuming a measurement accuracy of ±0.2K:

### Table 2 Accuracy of \( k_b \) when \( T_i - T_o = 12K \)

<table>
<thead>
<tr>
<th>( k_b )</th>
<th>( T_i ) (°C)</th>
<th>( T_o ) (°C)</th>
<th>Accuracy (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>6</td>
<td>5.5</td>
<td>0.45</td>
</tr>
<tr>
<td>0.6</td>
<td>7.2</td>
<td>6.6</td>
<td>0.55</td>
</tr>
<tr>
<td>0.7</td>
<td>8.4</td>
<td>7.5</td>
<td>0.65</td>
</tr>
<tr>
<td>0.8</td>
<td>9.6</td>
<td>8.6</td>
<td>0.75</td>
</tr>
<tr>
<td>0.9</td>
<td>10.8</td>
<td>9.6</td>
<td>0.84</td>
</tr>
</tbody>
</table>

### Table 3 Accuracy of \( k_b \) when \( T_i - T_o = 20K \)

<table>
<thead>
<tr>
<th>( k_b )</th>
<th>( T_i ) (°C)</th>
<th>( T_o ) (°C)</th>
<th>Accuracy (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>10</td>
<td>9.5</td>
<td>0.47</td>
</tr>
<tr>
<td>0.6</td>
<td>12</td>
<td>11.5</td>
<td>0.57</td>
</tr>
<tr>
<td>0.7</td>
<td>14</td>
<td>13.5</td>
<td>0.67</td>
</tr>
<tr>
<td>0.8</td>
<td>16</td>
<td>15.5</td>
<td>0.77</td>
</tr>
<tr>
<td>0.9</td>
<td>18</td>
<td>17.5</td>
<td>0.87</td>
</tr>
</tbody>
</table>

From Table 2 and Table 3 we can see that for the \( k_b \) range of 0.5 to 0.9 the difference in accuracy of the two is up to 4%. This number drops to 2% at the higher end of \( k_b \). It is therefore safe to use the inside/outside temperature difference of as low as 12K without losing much resolution. This can be clearly seen from Figure 3 where the error value of \( k_b \) is plotted against the inside/outside temperature difference for a \( k_b \) value of 0.6.

### 4. THE THERMAL BRIDGING CHART

A chart for inside temperature of 12°C is shown in Figure 2. In the chart, the \( x \) axis represents the outside air temperature; the left \( y \) axis indicates the \( k_b \) value. The values of \( k_b \) are represented by lines starting from 1/\( k_b \), i.e. when both inside and outside temperatures are 12°C. The right \( y \) axis is scaled from 0 to 1, corresponding to the situations when external surface temperature is equal to inside air temperature (\( k_b = 0 \)) and when the external surface temperature is the same as the outside air temperature (\( k_b = 1 \)).

Obviously, all temperatures and dew points must be between these two lines.

When the inside temperature is a constant, the surface temperature becomes a linear function of the outside temperature (Equation 2). Therefore each component can be represented by a straight line, from which the surface temperature can be easily found from the \( y \) axis for any given outside temperature (\( x \) axis).

The \( k_b \) factor of components can be easily found by extending the lines representing components to the right \( y \) axis.

The local dew point (the maximum ambient temperature that condensation occurs) is represented by points, i.e. dew point temperature (\( y \)) against ambient air temperature (\( x \)).

Whether a component will cause condensation can then be clearly seen by checking whether the line representing the component is above the dew point.

In the chart, the classification of \( k_b \) defined by BS EN 1886:1998 is also reserved (the areas separated by the corresponding \( k_b \) lines) for those conditions.

### 5. APPLICATION OF THE THERMAL BRIDGING CHART

This method has been used in our development process for air handling units to evaluate the thermal bridging property of components. The \( k_b \) factor of components has been obtained from both theoretical calculations and experimental methods.

Figure 4 shows the thermal bridging property of structural components air handling units together with the critical dew point temperatures at different locations extracted from the HVAC System Design Handbook [2]. Note that only two components with the highest and lowest \( k_b \) values are presented (the panel and the structural rails) for clarity as other components are in between.

At the development stage, the component with the lowest \( k_b \) value was first identified. Different designs of the component were then made to achieve higher values of \( k_b \) until it was well above the nominated dew points (design criteria). The \( k_b \) factor of each design was calculated theoretically. Selected designs were then prototyped and the \( k_b \) verified experimentally. As the particular component was improved other component became the focus (with lower \( k_b \)). This process was repeated to the components with lower \( k_b \) values until an optimized arrangement was found (in terms of both performance and cost).

Figure 4 shows the final stage of panels and rails as well as the original design of the rails. The improvement of rails is clearly shown. The final design of these components are within TB1 zone and well above the dew points, indicating that condensation would not occur for those conditions.
It is necessary to standardise the conditions of measurement so that the results are comparable and to a satisfactory accuracy. This should be considered in the development of the Australian version of the standard.

B. CONCLUSIONS

Based on both our theoretical analysis and experimental verification, the following conclusions can be made:

1. The concept of the thermal bridging factor $k_b$ introduced in BS EN 1886:1998 is appropriate for measuring thermal bridging property of air handling unit casing components.

2. It is appropriate to associate the $k_b$ factor to individual components of an air handling unit. This allows the designers to map the thermal bridging property of a unit in order to control, improve and balance the property among components. For the units it means better understanding and therefore higher confidence.

3. The temperature difference of 20k required by BS EN 1886:1998 for measurement of $k_b$ can be reduced to 12k with a satisfactory accuracy.

4. There is no difference in setting the inside temperature higher or lower than the outside temperature when measuring $k_b$.

5. Air movement affects the $k_b$ measurement and therefore needs to be controlled in a consistent manner when measuring $k_b$.

6. The thermal bridging chart provides an accurate and yet easy-to-use method for mapping the thermal bridging property of components and determining surface condensation.

7. Further standardisation is necessary to adapt the concept and define test conditions for the Australian applications.

About the Author

Gang Wei is the Mechanical and Development Engineer/QA manager for Air Design Pty Ltd (Supplier of air handling units and air movement equipment). His responsibilities include new product development, engineering design, applications engineering, testing, as well as maintaining the quality system.

Reference

2. The Australian Institute of Refrigeration Air Conditioning and Heating (Inc.) Hand Book, 2nd Ed 1995

6. DETERMINING $k_b$

As above mentioned the $k_b$ value of components can be obtained from either theoretical calculation or experimental measurement. Theoretical determination of $k_b$ varies depending on the complexity of the component and the way it is modeled. This will be dealt with elsewhere.

To measure the $k_b$ value of a component we need to create a temperature difference between the inside and out side air. Knowing that $k_b$ is independent of temperature and the temperature difference can be as low as 12k without compromising the measurement accuracy (refer to section 3 above). We can use either heating or cooling to achieve these temperatures. In the laboratory a box of ice or a heater with a suitable circulating fan can be placed inside the unit casing being tested. For installed units the temperature difference is normally readily available when the unit is running.

Once the temperature difference is established and becomes stable, the inside temperature, outside temperature and the temperature on the surface of components can be measured and recorded. Equation 2 can then be applied to calculate the $k_b$ value for each component.

7. DISCUSSIONS

The above method provides a useful tool that quantifies the thermal bridging property of components and evaluates it against surface condensation. Through a large number of measurements, both in our laboratory and from installed units, we found that a satisfactory accuracy can be achieved with a lower temperature difference than that required by BS EN 1886. However we did maintain a minimum temperature difference of 12k.

The accuracy of measurement can also be affected by the movement of air, as this alters the thermal property of the surface layer of air. Care should therefore be taken when the unit being measured is either installed externally or in a plant room where air is moving through the room. In our laboratory testing we managed to maintain an inside surface air velocity similar to that found in a running air handling unit. The outside air was kept as still as possible.