ISO 13768

Sign trouble leading to massive inconsistency and significant applicability reduction of many formulas in 2007 version

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THERMAL PERFORMANCE OF BUILDING COMPONENTS – DYNAMIC THERMAL CHARACTERISTICS – CALCULATION METHODS (ISO 13786:2007)

Sign trouble leading to massive inconsistency and significant applicability reduction of many formulas in 2007 version of the standard

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The problem

- Current ISO 13786:2007 misses the definition of thermal conductance
- Missing it leads to
  - missing the sign of the flow (the heat flow direction)
  - incorrect summation (missing matrix diagonals)
  - the law of energy conservation is not fulfilled (?)
  - formulas presented are inconsistent when compared to other standard (e.g. contradict those in ISO 10211)
  - significant internal inconsistencies too
  - formulas difficult to memorize due to "inherited sign error"
  - yields applicability of numbers calculated by magnitudes to single zone model only (and only magnitudes apply)

References

- On the storage of Heat in Building Components
  1993, Krec K.
- Amendment to the draft international standard ISO/DIS 13786; ISO/TC 163/SC 2
  2005, Krec K.

The problem – eq.4

- ISO 13786:2007 eq.4 states:

$$\widehat{\Phi}_m = \underline{\quad} L_{m,m} \cdot \widehat{\Theta}_m - L_{m,n} \cdot \widehat{\Theta}_n$$

- but it shall be (special case of 2 thermal zones only):

$$\widehat{\Phi}_m = -L_{m,m} \cdot \widehat{\Theta}_m - L_{m,n} \cdot \widehat{\Theta}_n$$

- or generally define the basic relation:

$$\widehat{\Phi}_m = -\sum_n L_{m,n} \cdot \widehat{\Theta}_n$$

The problem – eq.4

- Equations shall be valid for any arbitrary period length, including the constant case (0th harmonic)
- For constant case ISO 13786:2007 eq.4 yields:

$$\Phi_m = -L_{m,n} \cdot \Theta_m - L_{m,n} \cdot \Theta_n$$

$$= -L_{m,n} \cdot (\Theta_m + \Theta_n)$$

- but the **well known for 2 spaces only**:

$$\Phi_m = L_{m,n} \cdot \Theta_m - L_{m,n} \cdot \Theta_n$$

$$= L_{m,n} \cdot (\Theta_m - \Theta_n)$$

- i.e. eq.B.4 and also ISO 10211:2007 eq.7

Remark

- Remark: For the constant case (time-independent calculation) the law of energy conservation results in the relation:

$$\sum_n L_{m,n} = 0$$

- the summation runs on all spaces (<u>including m</u>)
- Respectively (and but) holds
for the **special case of 2 thermal zones <u>only</u>**:

$$L_{m,m} = -L_{m,n}$$

Inherited faults – eq.5

- Definition of the heat capacity – eq. (5) $$C_{\mathrm{m}} = \frac{1}{\omega}\left|L_{\mathrm{mm}} - L_{\mathrm{mn}}\right|$$ As a consequence of the incorrect equation (4) of the ISO 13786:2007, the above definition equation of the heat capacity has to be changed.

- Correct and consistent:
- For the **general case** of building constructions thermally **combining numerous thermal zones**, the definition of the heat capacity of zone m is given by

$$C_m = \frac{1}{\omega} \cdot \left| \sum_n L_{m,n} \right|$$

- Thus, for the **special case of only 2 zones** shall be:

$$C_m = \frac{1}{\omega} \cdot \left| L_{m,m} + L_{m,n} \right|$$

Remark

- For the constant case (time-independent calculation) the law of energy conservation

$$\sum_n L_{m,n} = 0$$

- or for the **special case of 2 thermal zones <u>only</u>** holds:

$$L_{m,m} = -L_{m,n}$$

- and thus the (**correct**) formula must immediately lead to the statement that the **heat capacity is zero for time independent calculations**.

$$C_m = \frac{1}{\omega} \cdot \left| \sum_n L_{m,n} \right| \qquad C_m = \frac{1}{\omega} \cdot \left| L_{m,m} + L_{m,n} \right|$$

Inherited faults – eq.8

- Definition of the areal heat capacity– eq. (8)

$$\chi_{\mathrm{m}} = \frac{C_{\mathrm{m}}}{A} = \frac{1}{\omega}\left|Y_{\mathrm{mm}} - Y_{\mathrm{mn}}\right|$$

- has to be changed.

- Correct and consistent for the **special case of only 2 zones** shall be:

$$\chi_m = \frac{C_m}{A} = \frac{1}{\omega} \cdot \left|Y_{m,m} + Y_{m,n}\right|$$

Inherited faults – eq.19, B.9, B.10

- Definition of thermal admittances – eq. (19), and (B.9), (B.10)
- have to be changed.

$$Y_{11} = -\frac{Z_{11}}{Z_{12}} \qquad Y_{22} = -\frac{Z_{22}}{Z_{12}}$$

- Correct and consistent for the **special case of only 2 zones** shall be:

$$Y_{1,1} = \frac{Z_{1,1}}{Z_{1,2}} \qquad Y_{2,2} = \frac{Z_{2,2}}{Z_{1,2}}$$

Inherited faults – eq.B.8

- In the course of the comparison of equation (B.8) with the matrix of thermal conductances the basic relation has to be considered!
- The vector of the area related heat losses: $\begin{pmatrix} \hat{q}_1 \\ -\hat{q}_2 \end{pmatrix} = \frac{1}{A} \cdot \begin{pmatrix} \hat{\Phi}_1 \\ \hat{\Phi}_2 \end{pmatrix}$
- then $\frac{\hat{\Phi}_1}{A} = -\frac{L_{1,1}}{A} \cdot \hat{\Theta}_1 - \frac{L_{1,2}}{A} \cdot \hat{\Theta}_2 = -Y_{1,1} \cdot \hat{\Theta}_1 - Y_{1,2} \cdot \hat{\Theta}_2$
- and $\frac{\hat{\Phi}_2}{A} = -\frac{L_{2,1}}{A} \cdot \hat{\Theta}_1 - \frac{L_{2,2}}{A} \cdot \hat{\Theta}_2 = -Y_{2,1} \cdot \hat{\Theta}_1 - Y_{2,2} \cdot \hat{\Theta}_2$
- where $L_{1,1} = A \cdot Y_{1,1} = \frac{A \cdot Z_{1,1}}{Z_{1,2}}$ and $L_{2,2} = A \cdot Y_{2,2} = \frac{A \cdot Z_{2,2}}{Z_{1,2}}$ (missing it in 2007 edition)
- immediately leading to:

$$Y_{1,1} = \frac{Z_{1,1}}{Z_{1,2}} \quad , \quad Y_{2,2} = \frac{Z_{2,2}}{Z_{1,2}} \quad \text{and} \quad Y_{1,2} = Y_{2,1} = -\frac{1}{Z_{1,2}}$$

Inherited faults – eq.B.13

- Finally – eq. (B.13)

$$\hat{\Phi}_{\mathrm{j}} = \sum_{\mathrm{k}} \left(L_{11,\mathrm{k}} \hat{\theta}_{\mathrm{j}} - L_{12,\mathrm{k}} \hat{\theta}_{\mathrm{k}} \right)$$

- has to be changed.

- Correct and consistent for any number of zones it shall be:

$$\hat{\Phi}_{j} = -\sum_{k} (L_{1,1,k} \cdot \hat{\Theta}_{j} + L_{1,2,k} \cdot \hat{\Theta}_{k})$$

Resolution

Add the definition of the
periodic (harmonic) thermal conductance

Definition of the periodic thermal conductance

- the general relation between the complex amplitude of the heat loss of thermal zone *m* and the complex amplitudes of air temperatures of the spaces in a building is given by:

$$\hat{\Phi}_m = -\sum_n L_{m,n} \cdot \hat{\Theta}_n$$

- the summation in *n* runs on all spaces (<u>including *m*</u>)
- for the **amplitude of the <u>heat loss</u>**, the heat flow rate is defined as positive when it enters the surface of the component

Backup

The definition of the

periodic (harmonic) thermal conductance

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Theory - 1

- The heat loss of a space *i* is given by integrating the heat flow density at the boundary of this space:

$$\Phi_i = \iint_{\Re_i} \vec{q} \cdot d\vec{a}$$

- the vector of the heat flow density is integrated over the boundary of space *i*.
- the surface element is oriented from the space toward the building component.
- this relation is valid for the constant case as well as for the periodic case (Φ and *q* are both complex amplitudes then)

Theory - 2

- With Fourier's law this can be rewritten to:

$$\Phi_i = -\iint_{\Re_i} (\lambda \cdot grad\,\Theta) \cdot d\vec{a}$$

Theory - 3

- The temperature at any point (x, y, z) of a construction:

$$\Theta(x,y,z) = \sum_j g_j(x,y,z) \cdot \Theta_j$$

- g_j (x,y,z) is the temperature weighting factor at the point (x, y, z) related to space j and Θ_j is the air temperature of the space j.
- this relation is valid for the constant case as well as for the periodic case (Θ and g are both complex then)

Theory - 4

- The earlier integral can by now rewritten to:

$$\Phi_i = -\sum_j \Theta_j \cdot \iint_{\Re_i} (\lambda \cdot grad\, g_j) \cdot d\vec{a}$$

- important note:
  the summation in *j* runs for all spaces (<u>including *i*</u>)
- this relation is valid for the constant case as well as for the periodic case (Φ, Θ and *g* are all complex then)

Theory - 5

- Extracting the integral part of the previous

$$L_{i,j} = \iint_{\Re_i} (\lambda \cdot grad\ g_j) \cdot d\vec{a}$$

- defines the **Thermal Conductance** for the **pair of spaces** *i* and *j*.
- integration is performed over the boundary of space i.
- g_j are the temperature weighting factors related to space *j* at the boundary of space *i*.
- this relation is valid for the constant case as well as for the periodic case (*L*, and *g* are both complex then)

Theory - 6

- With the definition equation for thermal conductances the **basic relation** connecting heat losses with air temperatures is given by:

$$\Phi_i = -\sum_j L_{i,j} \cdot \Theta_j$$

- the summation in *j* runs on all spaces (including *i*)

- this relation is valid for the constant case as well as for the periodic case (Φ, *L*, and Θ are all complex then)

Conclusio

Good replaced with Better