

Energy and buildings

Energy balance of a room

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Building energy balance
The building energy needs depend on several overlapping physical
phenomena:
• Heat conduction through the walls Building energy balance
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• Heat conduction through the walls
• Heat convection and radiant heat exchange on internal and external
surfaces phenomena:

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- **Building energy balance**

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phenomena:

 Heat conduction through the walls

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 **• Heat convection and radiant heat exchange on internal and external

sur Building energy balance**

The **building energy needs** depend on several overlapping physical

phenomena:

• Heat conduction through the walls

• Surfaces

• Internal generation of heat due to people and appliances

• Sola
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Heat conduction through the envelope

Heat conduction is a heat transfer

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Frachanism between two systems (either

through the envelope
Heat conduction is a heat transfer
mechanism between two systems (either
solids, liquids or gases) at different
temperatures with no significant mass
transfer and responds to the Fourier Law through the envelope

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$$

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Heat transfer by convection

Thermal convection

Thermal convection

Thermal convection

Thermal convection is a heat exchange

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Systems placed in contact with each o Thermal convection is a heat exchange mechanism that takes place between two systems placed in contact with each other and at different temperatures, where at least one transfer by convection

Thermal convection is a heat exchange

mechanism that takes place between two

systems placed in contact with each other and
 T_s at different temperatures, where at least one

of the two systems

of the two systems is **fluid**.
A necessary condition for this energy exchange to take place is that there is relative motion between the two systems.

$$
q = h_c A (T_s - T_{\infty})
$$

Heat transfer by radiation
The emissivity ϵ of a material expresses the global emission E of the
material relative to the global emission of a black body at the same
temperature E_b . Heat transfer by radiation
The emissivity ϵ of a material expresses the global emission E of that
material relative to the global emission of a black body at the same
temperature E_b .
 $\frac{\text{surface} \cdot \text{surface} \cdot \text{surface} \cdot \text{surface} \cdot \text$ Heat transfer by radiation
The emissivity ϵ of a material expresses the global emission E of that
material relative to the global emission of a black body at the same
temperature E_b .
 $\frac{S_{\text{surrounding}}}{T_{\text{near}}}$
 $\frac{q_{rad}$ temperature E_h . the global emission E of that
of a black body at the same
 $q_{rad} = \epsilon \sigma A_s (T_s^4 - T_{surr}^4)$

$$
q_{rad} = \varepsilon \,\sigma A_s (T_s^4 - T_{surr}^4)
$$

$\begin{picture}(180,10) \put(0,0){\line(1,0){180}} \put(10,0){\line(1,0){180}} \put(10,0){\line(1,0){180}} \put(10,0){\line(1,0){180}} \put(10,0){\line(1,0){180}} \put(10,0){\line(1,0){180}} \put(10,0){\line(1,0){180}} \put(10,0){\line(1,0){180}} \put(10,0){\line(1,0){180}} \put(10,0){\line(1,0){180}} \put(10,0){\line(1,0){180}}$ Incident solar radiation Transmitted solar radiation Absorbed solar radiation ance of the building envelope

reflected solar

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reflected solar

reflected Reflected solar **conduction and the conduction and the conduction and the conduction and the conduction** nder and the Magnetian Scheme and the Solar radiation

Solar radiation

Scheme and the schange

Scheme with indoor air

Scheme internal surfaces Transmitted

solar radiation

Convective heat exchange

Radiant heat exchange

Radiant heat exchange with

Radiant heat exchange with

other internal surfaces adam ce of the building envelope

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Solar radiation

Solar radiation

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other internal surfaces alance of the building envelope

Iding components

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radiation

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Heat balance of the building envelope

Opaque building components: sol-air temperature

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Opaque building components: sol-air temperature exchange with ℎ, ௦ [−] − α ௦௦ = ℎ, ௦ [−] ௦ି ℎ, ௦ି [−] = α ௦௦ ି = + , Heat balance of the building envelope

Heat balance of the building envelope

Opaque building components: sol-air temperature

Si^{n temperature}

building envelope

in surfaces

View factor F_{k-j} : fraction of the radiation

that reaches directly the k-th surface from

the j-th surface
 $F_{k-j} = \frac{1}{2\pi S_j} \iint_{S_k, S_j} \left(\frac{\cos \varphi_k \cos \varphi_j}{d^2} \right) dS_k dS_j$ View factor F_{k-j} : fraction of the radiation building envelope

un surfaces

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$$
F_{k-j} = \frac{1}{2\pi S_j} \iint_{S_k S_j} \left(\frac{\cos \varphi_k \cos \varphi_j}{d^2} \right) dS_k dS_j
$$

$$
q_{k-j} = A_k F_{k-j} \sigma \left(T_k^4 - T_j^4 \right) = A_j F_{j-k} \sigma \left(T_k^4 - T_j^4 \right)
$$

Heat balance of the building envelope
Radiant heat exchange between surfaces

Heat balance of the building envelope

Radiant heat exchange between surfaces

Charts with pre-calculated view factors
 F_{k-j} for given geometries of the mutual

connections ilding envelope

urfaces

Charts with pre-calculated view factors
 F_{k-j} for given geometries of the mutual

connections
 $\overbrace{f_{k-j}^{(1)}}$ F_{k-i} for given geometries of the mutual connections

Heat balance of the building envelope
Thermal radiation to the sky
The radiant heat emission of the j-th

The radiant heat emission of the j-th outer surface of the building towards the sky can be expressed by:

$$
q_{sky,j} = \varepsilon_j \sigma A_j F_{j-sky} (T_j^4 - T_{sky}^4)
$$

Solution Solution Symbol Set the Set of Set of the set of the set of the set of the building towards

sky can be expressed by:
 $q_{sky,j} = \varepsilon_j \sigma A_j F_{j-sky} (T_j^4 - T_{sky}^4)$

e effective sky temperature T_{sky}

be calculated bas **ilding envelope**
The radiant heat emission of the j-th
outer surface of the building towards
the sky can be expressed by:
 $q_{sky,j} = \varepsilon_j \sigma A_j F_{j-sky} (T_j^4 - T_{sky}^4)$
The effective sky temperature T_{sky}
can be calculated based The effective sky temperature T_{sky} can be calculated based on the local air temperature and relative humidity (Bliss, 1961)

ss, 1961)

ding envelope
 $q_{gnd,j} = ε_jσA_jF_{j-gnd}(T_j^4 - T_{gnd}^4)$
 $F_{j-sky} = \frac{1-cos\theta}{2}$; $F_{j-gnd} = 1 - F_{j-sky}$
 $q_{gnd,j} + q_{sky,j} = ε_jσ A_j(...)$ $T_{\rm grad}^4$)) and $\overline{}$ and $\overline{}$ $F_{j-sky} = \frac{1-cos\theta}{2}$; $F_{j-gnd} = 1 - F_{j-sky}$ 2 \int -gnu \int -sky \textsf{lope}
 $\begin{aligned} i &= g_{rad}(T_j^4 - T_{g_{rad}}^4) \ j &= F_{j-g_{rad}} = 1 - F_{j-sky} \ \textsf{mod} \ A_j(\ldots) \ \Delta R \end{aligned}$ ding envelope
 $q_{gnd,j} = \varepsilon_j \sigma A_j F_{j-gnd} (T_j^4 - T_{gnd}^4)$
 $F_{j-sky} = \frac{1 - cos\theta}{2}$; $F_{j-gnd} = 1 - F_{j-sky}$
 $q_{gnd,j} + q_{sky,j} = \varepsilon_j \sigma A_j (...)$
 $\frac{q_{gnd,j} + q_{sky,j}}{A_j} = \varepsilon_j \Delta R$

ASHRAE Handbook suggests $\Delta R = 63$ W/m² $\frac{1}{j}^{4} - T_{gnd}^{4}$
 $\frac{1}{k} = 1 - F_{j-sky}$

(...)

= 63 W/m² $q_{gnd,j} + q_{sky,j} = \alpha \Lambda R$ A_j $\qquad \qquad$ $\begin{array}{l} \mathbf{v} \mathbf{e} \vert \mathbf{ope} \ \mathbf{v} \mathbf{A}_j F_{j-gnd} (T_j^4 - T_{gnd}^4) \ \frac{\cos\theta}{2} \, ; \, F_{j-gnd} = 1 - F_{j-sky} \ \frac{\cos\theta}{2} \, ; \, F_j \, = \, \varepsilon_j \, \alpha \, f_j (\ldots) \ \end{array}$
= $\, \varepsilon_j \, \Delta R$
ook suggests ΔR = 63 W/m² ΔR ding envelope
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ASHRAE Handbook suggests $\Delta R = 63$ W/m² (BIISS, 1901)

balance of the building envelope

radiation to the sky
 $F_{root-sky} = 0.93$
 $q_{gnd,j} = \varepsilon_f \sigma A_j F_{j-gnd} (T_j^4 - T_{gnd}^4)$
 $F_{j-sky} = \frac{1-cos\theta}{2}; F_{j-gnd} = 1 - F_{j-sky}$
 $q_{gnd,j} + q_{sky,j} = \varepsilon_f \sigma A_j (.)$ ance of the building envelope

stion to the sky
 $q_{gnd,j} = \varepsilon_j \sigma A_j F_{j-gnd} (T_j^4 - T_{gnd}^4)$
 $F_{j-sky} = \frac{1-\cos\theta}{2}$; $F_{j-gnd} = 1 - F_{j-sky}$
 $q_{gnd,j} + q_{sky,j} = \varepsilon_j \sigma A_j (.)$
 $\frac{q_{gnd,j} + q_{sky,j}}{A_j} = \varepsilon_j \Delta R$

ASHRAE Handbook suggests $\Delta R =$

Heat balance of the building envelope

Opaque building components: sol-air temperature with thermal radiation to the sky

Convective heat

exchange with

Heat balance of the building envelope	
Opaque building components: sol-air temperature with thermal radiation to the sky	
Convectioned scalar	$h_{c,e}(T_s - T_e) - \alpha f_{sn}I_s + \epsilon \Delta R = h_{c,e}(T_s - T_{sol-a})$
Comvetive hat	$h_{c,e}(T_{sol-air} - T_e) = \alpha f_{sh}I_s - \epsilon \Delta R$
Thermal	
Imelation to the sky	
Thermal	
Indiation to the sky	
Re	$T_{sol-air} = T_e + \frac{\alpha f_{sh}I_s}{h_{c,e}} - \frac{\epsilon \Delta R}{h_{c,e}}$
Heat balance of the indoor air	
Comvetive heat exchange with internal surfaces of the building envelope $q_{c,i}$	
Quilling envelope $q_{c,i}$	
Quilling envelope $q_{c,i}$	
Quilling envelope $q_{c,i}$	
Quilling envelope $q_{c,i}$	
Quilling the two slope $q_{c,i}$	
Quilling the two slope $q_{c,i}$	

- building envelope $q_{c,i}$
- $\frac{w_{SIR}}{h_{c,e}} = \frac{w_{SIR}}{h_{c,e}}$
Convective heat exchange
with internal surfaces of the
building envelope $q_{c,i}$
Convective heat exchange
with internal heat sources
such as lights and appliances
 $q_{c,int}$ independent of the convective heat exchange

in this internal surfaces of the

building envelope $q_{c,i}$

• Convective heat exchange

with internal heat sources

such as lights and appliances
 $q_{c,int}$

• Convective heat e Convective heat exchange
with internal surfaces of the
building envelope $q_{c,i}$
convective heat exchange
such as lights and appliances
 $q_{c, int}$
Convective heat exchange
with HVAC system $q_{c,p}$
Convective heat exchange Convective heat exchange
with internal surfaces of the
building envelope $q_{c,i}$
Convective heat exchange
with internal heat sources
such as lights and appliances
 $q_{c,int}$
Convective heat exchange
with HVAC system $q_{c,p}$
 $q_{c, int}$ incertainty
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• Convective heat exchange

with internal surfaces of the

building envelope $q_{c,i}$

• Convective heat exchange

such as lights and appliances
 $q_{c,int}$

• Convective heat exchange

with HVAC system inceptive heat exchange

• Convective heat exchange

with internal surfaces of the

building envelope $q_{c,i}$

• Convective heat exchange

such as lights and appliances
 $q_{c,int}$

• Convective heat exchange

with HVAC syst Convective heat exchange
with internal surfaces of the
building envelope $q_{c,i}$
Convective heat exchange
with internal heat sources
such as lights and appliances
 $q_{c,int}$
Convective heat exchange
with HVAC system $q_{c,p}$

- with HVAC system $q_{c,p}$
- infiltration q_g

Overall heat balance of the room

Heat conduction through the building components (2)

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-
- Indoor air stratification neglected (single air node)

 Steady-state heat conduction neglected (single air node)

 Steady-state heat conduction through the walls

 Uniform distribution of the radiation in the room (s **Dyerall heat balance of the room Main assumptions**
• Indoor air stratification neglected (single air node)
• Steady-state heat conduction through the walls
• Uniform distribution of the radiation in the room (solar, mutua **Verall heat balance of the room**
Transmark of the room
Indoor air stratification neglected (single air node)
Steady-state heat conduction through the walls
Uniform distribution of the radiation in the room (solar, mut

Overall heat balance of the room
Main assumptions
• Indoor air stratification neglected (single air node)

Main assumptions

-
- **Indoor air stratification neglected (single air node)**
• Indoor air stratification neglected (single air node)
• Uniform distribution of the radiation in the room (solar, mutual and from internal sources)
• $f_{int,c}$ is **Dverall heat balance of the room**
Main assumptions
• Indoor air stratification neglected (single air node)
• Uniform distribution of the radiation in the room (solar, mutual and
• f_{int,c} is the convective fraction of **is the convertion of the convertion**
is the convertional symmetric ration of the radiation in the room (solar, mutual and
internal sources)
is the convective fraction of internal heat gains
the convective fraction of heat Train that the convertion of the convertions assumptions
or air stratification neglected (single air node)
form distribution of the radiation in the room (solar, mutual and
internal sources)
is the convective fraction of h
-
- $f_{p,c}$ is the convective fraction of heat emitted by the HVAC system

\n- \n
$$
I_{int,c}
$$
 is the convective fraction of the initial heat by the HVAC system
\n- \n $f_{p,c}$ is the convective fraction of heat emitted by the HVAC system
\n
\n\n- \n Overall heat balance of the room\n
\n- \n $-h_{ce,k}S_k(T_{sek} - T_{sol,air}) + Sk \cdot f(T_{slk} - T_{se,k}) = 0$ \n
\n- \n $-S_k \cdot f(T_{sik} - T_{sek}) + q_{c,i,k} + q_{sol,k} + (1 - f_{\text{int},c})q_{\text{int},k} + (1 - f_{p,c})q_{p,k} - q_{r,k} = 0$ \n
\n- \n $-q_{c,i,k} + f_{\text{int},c} q_{\text{in},k} + f_{p,c} q_{p,k} + m_a c_{p,a} (T_e - T_a) = \rho_a V_a c_{p,a} \frac{dT_a}{dt}$ \n
\n

Example Analyze and semplify the problem
An example: the hall of a congress palace Analyze and semplify the problem
An example: the hall of a congress palace
And the hall of a congress palace

40

42

41

$$
\begin{aligned}\n\text{(1)} \quad & \frac{(t_f - t_w)}{R_{Floor}} + h_R(t_f - t_{CeD}) + h_{CD}(t_f - t_a) = q_I + I_t \\
\text{(2)} \quad & h_{CD}(t_a - t_f) + \frac{G_a C_p}{S_f} \cdot (t_a - t_{a,in}) + h_{CU}(t_a - t_{CeD}) = q_p + q_{c,int} \\
\text{(3)} \quad & h_R(t_{ceD} - t_f) + h_{CU}(t_{CeD} - t_a) + \frac{(t_{ceD} - t_{ceU})}{R_{ceil}} = \frac{I_a}{2}\n\end{aligned}
$$

$$
\textcircled{4}\quad \frac{(t_{ceU} - t_{ceD})}{R_{ceil}} + h_e(t_{ceU} - t_{amb}) = \frac{I_a}{2}
$$

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Underwood C.P References
EN ISO 13790:2008. Energy performance of buildings - Calculation of energy use for space heating
and cooling.
Michele De Carl, Simulation and numerical methods. Energy in buildings and Underwood C.P., Yie KW.H. https://wufi.de/literatur/Karagiozis,%20K%C3%BCnzel%20et%20al%20-%20WUFI-ORNL%20IBPA%20North%20American%20Hygrothermal%20Model.pdf