### Air thermal balance: Convection

Convection is the heat exchange that governs the air temperature in the indoor environment, reflecting directly on people’s thermal sensation and, consequently, in the air conditioning demand. It is feasible to obtain convection thermal balance in an outdoor environment. Still, surface thermal balance is more applicable for this external analysis, which is discussed in the next section.

In indoor air, convection heat balance is calculated by the sum of all the convective heat exchanges between surfaces, internal loads, and air, as Equation (1) shows. In this equation, q”s (opaque and glazed surfaces) plus q”s, glass (window frame surfaces) represents the heat flow between surfaces and air, q”­inf,out is heat gain or loss due to natural ventilation or crack infiltration from outdoor air, q”inf,int is heat gain or loss due natural ventilation or crack infiltration from adjacent zones air, q”syst is related to cooling/heating load from a mechanical system, and q”IL is heat added to the air by internal sources (e.g., people, light, and equipment).

|  |  |
| --- | --- |
|  | (1) |

Building performance simulation by EnergyPlus provides the heat exchanges present in Equation 1 in a detailed or simplified way through the output variable file [15]. Each heat exchange is obtained in the detailed output, while in the simplified output, some heat exchanges are summed and presented in a single output. For example, envelope surface convection is only one output for the zone, and it needs to be possibly understood which surface is responsible for adding or removing more heat from zone air. Table 3 shows the heat exchange and EnergyPlus outputs (version 22.2 [2]) in a detailed way. Simplified outputs are not covered in this study.

Table 3. Convective heat exchanges on EnergyPlus (version 22.2) detailed outputs.

|  |  |  |
| --- | --- | --- |
| **Heat exchange** | **EnergyPlus output**  **(Watt unit)** | **Description** |
| **q"s** | Surface Inside Face Convection Heat Gain Rate¹ | It represents the convective heat transferred by surfaces and is obtained for each surface (opaque or glazing).  A negative value indicates heat is transferred from the surface into the air. Thus, it is necessary to multiply these values by -1 in Equation 1 to change this direction. |
| **q"s,glass** | Surface Window Inside Face Frame and Divider Zone Heat Gain Rate | It represents the heat transferred by frame and divider surfaces, thus is obtained for each window or glass door surface. If negative, it indicates heat is transferred from the air to the surface. |
| **q"IL** | Zone Total Internal Convective Heating Rate | Always positive, it indicates the amount of heat added to the indoor air due to internal sources such as lighting, people, and equipment. It is obtained for each thermal zone. |
| **q"inf,gain,out** | AFN Zone Ventilation Sensible Heat Gain Rate | Always positive, it represents the heat added into indoor air by airflow from exterior windows and doors. It is obtained for each thermal zone. |
| **qinf,loss,out** | AFN Zone Ventilation Sensible Heat Loss Rate¹ | Always positive, it represents the heat removed from indoor air by airflow from exterior windows and doors. It is obtained for each thermal zone. Multiply these values by -1 in Equation 1. |
| **q"inf,gain,int** | AFN Zone Mixing Sensible Heat Gain Rate | Always positive, it represents the heat added into indoor air by airflow from interior windows and doors (adjacent zones). It is obtained for each thermal zone. |
| **q"inf,loss,int** | AFN Zone Mixing Sensible Heat Loss Rate¹ | Always positive, it represents the heat removed from indoor air by airflow from interior windows and doors (adjacent zones). It is obtained for each thermal zone. Multiply these values by -1 in Equation 1. |
| **q"syst,cool** | Zone Air System Sensible Heating Rate | Always positive, it represents the heat added into indoor air by a mechanical system to maintain air temperature in some setpoint value. It is obtained for each thermal zone. |
| **q"syst,heat** | Zone Air System Sensible Cooling Rate¹ | Always positive, it represents the heat removed from indoor air by a mechanical system to maintain air temperature in some setpoint value. It is obtained for each thermal zone. Multiply these values by -1 in Equation 1. |
| ¹In Equation 1, it is necessary to multiply these values by -1. | | |

The output Zone Total Internal Convective Heating Rate is the sum of Zone Lights Convective Heating Rate, Zone People Convective Heating Rate, and Zone Electric Equipment Convective Heating Rate, which represents the heat gains from lights, people, and electric equipment (gains from other types of equipment also could be obtained). But, since internal gains are fixed, varying only in the period of use, in this study, only the total internal gains are used.

### Opaque surface thermal balance: Radiation, Conduction, and Convection

Convection thermal balance is a way to understand which building element is responsible for increasing or decreasing internal temperatures. However, some detail still needs to be clarified. For example, analyzing the annual surface heat exchanges, the floor adds the most heat to air throughout the year. Still, it is unclear if this behavior is because of the floor's constructive element or solar radiation absorbed and emitted by the floor’ surface. Then, surface thermal balance is required to understand these heat exchanges and improve thermal and energy efficiency strategies that could be applied in building projects.

From the energy conservation law, energy is neither created nor destroyed, but energy is only transformed from one to another. In surface thermal balance, this principle occurs as in Fig. 4. This example shows the heat fluxes when the wall’s external surface has a higher superficial temperature than the internal surface because the conduction into the wall flows from the external surface to the internal surface. Resembling convection thermal balance, the surface thermal balance has its equation for the internal surface, as Equation (2). EnergyPlus provides these outputs for each surface, as Table 4 shows. Describing variables present in Equation (2), q”αsol,out represents heat absorbed by surface from solar radiation, q”LWR,out is heat absorbed by longwave radiation from environment surfaces and ground or emitted to the environment, q”conv,out is heat added or removed by convection, and there is q”cond,out which is the heat flux from the external surface to the interior of the constructive component or vice versa.

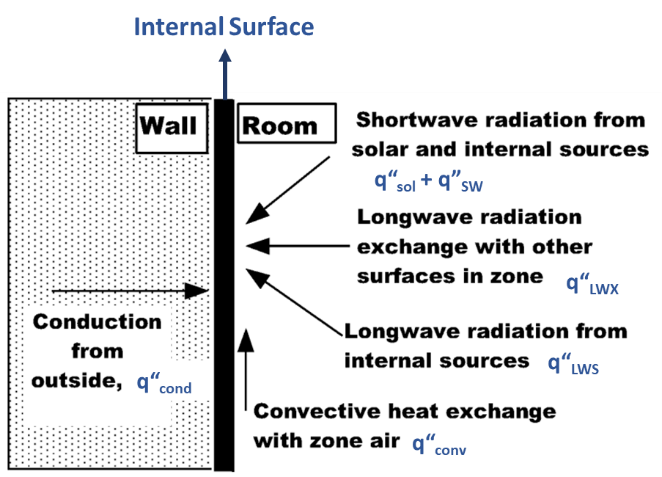


Fig. 4. Surface thermal balance (adapted from Engineering Reference EnergyPlus Version 22.2 [14]).

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| --- | --- |
|  | (2) |

Table 4. Surface heat exchanges on EnergyPlus outputs.

|  |  |  |
| --- | --- | --- |
| **Heat exchange** | **EnergyPlus output** | **Description** |
| **q"conv** | Surface Inside Face Convection Heat Gain Rate [W] | It represents the convective heat from surfaces. A negative value indicates heat is transferred from the surface into the air. |
| **q"cond** | Surface Inside Face Conduction Heat Transfer Rate [W] | It represents the conductive heat from surfaces. A negative value indicates heat is transferred from the surface’s inside face into the element core. |
| **q"sol** | Surface Inside Face Solar Radiation Heat Gain Rate [W] | It indicates the heat the surface absorbs by incident solar radiation passing through exterior windows. It is always positive. |
| **q"LWX** | Surface Inside Face Net Surface Thermal Radiation Heat Gain Rate [W] | It indicates heat exchanges between surfaces by longwave infrared thermal radiation. If negative, it indicates heat is emitted from the surface to other surfaces in the zone. |
| **q"LWS** | Surface Inside Face Internal Gains Radiation Heat Gain Rate [W] | It indicates heat that the surface absorbs by longwave thermal radiation from internal sources (e.g., lights, electric equipment, and people). It is always positive. |
| **q"SW** | Surface Inside Face Lights Radiation Heat Gain Rate [W] | It indicates heat that the surface absorbs by shortwave radiation from electric lights. It is always positive. |

Outputs present in Table 4 describe heat exchanges in opaque surfaces. In the case of glazing surfaces, there are five outputs for representing convection and radiation that enters the zone through exterior windows or is absorbed by windows. But, in this study, window thermal balance needs to be described and analyzed in detail. In contrast, the solar radiation absorbed by surfaces already shows the exterior window's impact on thermal balance.

### Heat Exchanges Index

Absolute values are obtained in both the air thermal balance and in opaque surface thermal balance. Therefore, these values are not easily interpreted, and an index was created to understand which heat exchanges are more important in each thermal heat balance for the interesting period. This index was called Heat Exchange Index (HEI) and was calculated separately for each gain and loss. HEI was calculated considering three time periods: hourly, monthly, and annual. HEI value is between 0 and 1, where values closer to 0 means that its heat exchange has zero or lower impact on room thermal balance, but values closer to 1 mean that its heat exchange has a higher impact.

HEI is calculated separately for air and surface thermal balance because air thermal balance requires understanding which point adds or removes more heat from the room’s air. Still, in surface thermal balance, heat transfer is the main analysis. HEI calculation for air thermal balance is according to Equations (3)-(4), where the x in HEIx,gain and q”x,gain represent one of the possible gains from each surface (from Table 3: q”s for opaque surfaces and q”s + q”s,glass for glazed surfaces), internal loads (from Table 3: q”IL), or heat exchanges from air or system (from Table 3: q”inf,gain,out, q”inf,gain,int, or q”syst,heat), and the x in HEIx,loss and q”x,loss represent one of the possible losses from each surface (from Table 3: q”s for opaque surfaces and q”s + q”s,glass for glazed surfaces), or heat exchanges from air or system (from Table 3: q”inf,loss,out, q”inf,loss,int, or q”syst,cool), at least, the and represents the sum of all gains and losses, respectively, that occurs on the air room during a period. For surface thermal balance, the HEI calculation is according to Equations (5)-(6), where the sf in HEIsf,gain represents one of the possible gains from each opaque surface and determined heat transfer (Table 4: all the parameters) and the sf in HEIsf,loss and q”sf,l the oss represents one of the possible losses from each opaque surface and determined heat transfer (from Table 4: q”conv, q”cond, or q”LWX), at least, the and represents the sum of all gains and losses, respectively, that occurs on each surface during a period.

|  |  |
| --- | --- |
|  | (3) |
|  | (4) |
|  | (5) |
|  | (6) |