THERMAL ANALYSIS AND THE ADMITTANCE METHOD

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The aim of this article is to explain how the CIBSE Admittance method for thermal analysis is implemented in Ecotect and to discuss its advantages and disadvantages. This is so that you can better understand its results when applied to your own models. It also explains some of the quirkier aspects of the method and shows how to analyse even the most complex effects.

INTRODUCTION

As in many aspects of life, no single solution is entirely suited to every conceivable problem. So it is with thermal analysis - there are quite a few methods or solutions out there, but each have their own set of advantages and disadvantages that make them suitable to some situations and less so for others. Thus, whilst Ecotect uses the CIBSE Admittance Method for its internal thermal analysis, it encourages you export your Ecotect model directly to a range of other thermal analysis tools such as *EnergyPlus*, *ESP-r* and *HTB2* to essentially get a second opinion and compare results.

Simulation and Accuracy

By definition, all simulation tools are based on some level of simplification of reality. Given the complexity of real systems, the main aim of a simulation method is to extract and model the most important relationships within a system whilst ignoring the less significant and unimportant ones - thereby encapsulating the main characteristics of that system.

Whilst it is possible to build highly intricate and sophisticated mathamatical simulation models which may be very accurate, such models usually have fundamental limitations, are the hardest and most demanding to use and, especially at the earliest stages of design, there is usually insufficient precise input data to warrant such accuracy. Thus a perfectly accurate simulation model is not always the ultimate goal - there are many rules of thumb widely used in the building industry have no real physical basis, yet applying them generally produces better buildings.

Ecotect implements the Chartered Institute of Building Services Engineers (CIBSE) Admittance Method as laid out in CIBSE Guide A (CIBSE 1999) [1], using a method for deriving temperature profiles originally outlined by Steve Szokolay in his book '*The Thermal Design of Buildings*' [2].

This is a widely used and very robust method - though it is only a pseudo-dynamic model and quite simple in concept. However it is

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number of interacting zones and sufficiently accurate for building services engineers in many parts of the world to use it for load calculations and HVAC sizing. It is by no means perfect and has several unique little quirks - but then so does every other thermal simulation method.

HOW IT WORKS

Imagine the simplest of buildings - a single room with four brick walls, a flat roof, a concrete floor slab on the ground, two windows and a door.

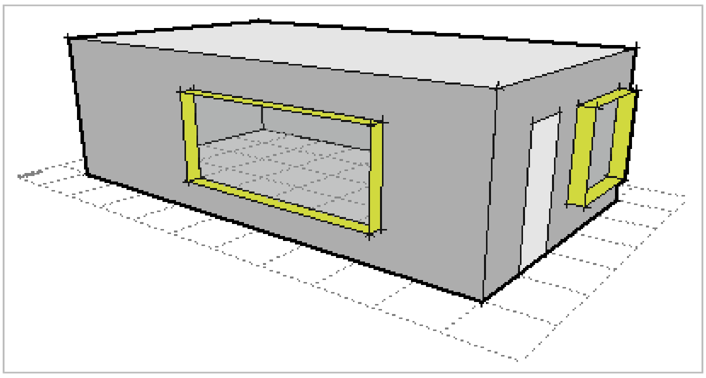

Figure 1 - Simple single-zone thermal model with two windows and a single door.

There are really only three ways that heat can actually flow in to or out of this building:

Ventilation Loss
Air leaking out through cracks and gaps in its construction as well as the porous nature of many materials.

Fabric Loss
Conduction, convection and radiation through the walls, floors and roof of the building.

Solar Gain
Short-wave solar radiation entering in through transparent appertures in the facade.

Thus we can characterise much of the thermal behaviour of such a building using only the resistance of its fabric to heat flow and the number of air change rates per hour due to infiltration / ventilation under different conditions.

[tex]Q = U A \delta T + 0.33 N V \delta T[/tex]
Here **Q** represents the total heat loss/gain whilst **U** is the area weighted average external U-Value, **A** the total external surface area, **T** the temperature difference between inside and outside, **N** the number of air changes per hour and **V** the internal air volume of the building.

Heating Things Up

If we now add a heater inside the building and make all the fabric well insulated and gaps well sealed, more heat could be added to the zone than could escape from it - resulting in an increasing internal temperature. However, the greater the temperature difference between inside air and outside air, the greater the overall heat flow. This is because heat flow through any element of the fabric is directly proportional to the temperature difference between its two sides. Thus internal temperatures will increase until the temperature difference across the fabric is such that the heat flowing out of the building is equal to the heat being generated inside - a state of thermal equilibrium.

On the other hand, if the building fabric was poorly insulated with many gaps and cracks, more heat would be able to flow out over any given time period - so the internal temperature at which thermal equilibrium occured would be much lower.

Cooling Things Down

If we make the system dynamic by suddenly turning off the heater, logic would suggest that the heat would continue to flow out and the building would quickly return to outside air temperature. However, because the walls might be made of brick and the floor concrete, the building could contain a lot of thermal mass that was able to absorb heat into its structure whilst the inside air temperature was high. As the inside air leaks out and internal temperatures tend towards outside air temperature, the heat that was flowing from a hot internal surface to a relatively cold external surface now finds itself with a relatively cold surfaces on both sides.

As a result, some of that heat starts flowing back towards the inside surface and then out into the space. As the thermal mass of 1kg of brick is equivalent to about 1500kg of air (roughly 1265m3), any heat released from the structure can make a huge difference to internal air temperatures.

Dynamic Behaviour

To model this behaviour, we are going to need the heat flow coefficients of each surface (its **U-value** - given in W/m2K) as well as some idea of its dynamic response. This response will depend on the specific heat of the material, its density, the speed with which it conducts heat within itself, its porosity and the ability of its surfaces to absorb and emit heat. All of these elements can be encapsulated into three measurable and calculable characteristics:

1. **Admittance** (W/m2K)
   The ability of a material to admit, retain and emit heat.

2. **Thermal Lag** (hours)
   The time taken for heat to travel from one side of the building element to the other.

3. **Thermal Decrement** (ratio 0-1)
   The relative amplitide of a temperature pulse on one side of the material when it reaches the other side.

Together with the U-value, these are the four basic characteristics of materials in the Admittance Method. Obviously there are some other important factors, such as the solar absorptance of surfaces and the solar transmittance of glazings, however these four form the core of the dynamic behaviour of the building.

[**Insert Image Here**]

Figure 4 - Image showing four core values.

Temperature Swing About the Mean

If we assume that in a completely static environment, where the outside temperature is exactly the same for weeks on end, any unoccupied building will eventually settle to an internal air temperature exactly the same as the outside air temperature (assuming no internal loads), then we can also assume that if the outside air temperature fluctuates periodically, then the internal air temperature of any building will always tend towards the overall average outdoor temperature. It may fluctuate due to influences from outside, but it will still only fluctuate about this mean temperature.

[**Insert Image Here**]

Figure 5 - Image showing mean temperature.

This assumption gives us a basis on which to work when determining exactly what the effect of variations in external conditions might be on the internal air temperature. For example, if we know how much solar radiation is entering through the windows at any particular time, then we can quickly calculate the corresponding heat gain. Based on the average internal temperature, the amount of heat loss from the buildng (U-Value) and its ability to absorb and re-release heat (Admittance), we can quite accurately predict the likely rise in internal temperatures.

Of course solar gains through glass are close to instantaneous. If that same solar gain heats up the external surface of a brick wall, for example, its internal effect will not be felt until it passes through the entire thickness of the wall - which could take up to 8 hours (Lag) and usually results in a significant loss (Decrement).

Thus, to calculate the internal temperature at any specific time, account needs to be taken of the lag and decrement of every exposed material in each zone (and the corresponding external temperature and incident solar gain 'lag' hours ago), the current external temperature and ventilation/infiltration rates, any current solar gains through exposed windows or transparent surfaces, and any internal loads due to occupants or equipment. All this gives the total instantaneous heat gain which, as the heat loss rate and daily average temperature is known, can be used to quickly calculate the internal temperature. If this is done every hour, a dynamic internal temperature profile can be generated.

FURTHER EXPLANATION

As mentioned previously, the Admittance Method has its own set of quirks and idiosyncracies. These are not necessarily problems or inaccuracies, but require some additional explanation.

Solar Gains and Environment Temperature

The standard Admittance Method does not track solar radiation through windows and on to specific internal surfaces (not many thermal simulation tools actually do). Incident solar gains on any window basically become an instantaneous space load, meaning that they have an immediate effect on internal temperatures. The resulting temperature increase is then absorbed into internal surfaces based on the Admittance value of each material, meaning that this forms the transmission mechanism between windows and the internal building fabric.

[**Insert Image Here**]

Figure 6 - Use of alternating solar gain factors.

It is fundamentally important at this point to understand that the internal temperature calculated by the Admittance Method is **NOT** an air temperature. It is an environment temperature formed from components of both mean radiant temperature (basically area weighted surface temperatures) and air temperature - making it more applicable to comfort analysis than a straight air temperature.

[**Insert Image Here**]

Figure 7 - Formula for Environmental Temperature (Tenv).

Whilst in reality solar radiation may not instantly raise the internal air temperature, when it falls on a surface it will definitely raise its surface temperature, thus increasing the mean radiant temperature in the space and therefore also the environment temperature. From a comfort or environment temperature perspective, it is highly likely that a zone's temperature graph in Ecotect will suddenly jump 6 or so degrees the moment the Sun rises and shines in through an east-facing window, despite the effects of a night-purge ventilation system the night before.

[**Insert Image Here**]

Figure 8 - Image of solar gain on a surface increasing its temperature.

What this means is that you cannot directly compare the reading from a dry bulb (air) temperature thermometer with those shown in Ecotect's temperature graph. Even if you could graph air temperatures, they would be the spatial average for each zone. In a real space a thermometer would most likely show a different value when closer to a window than when placed at the centre of the room. Thus it would not be a valid comparison even if you were comparing the same metric. For a detailed discussion of this, see the Making a Thermal Comparison article.

[**Insert Image Here**]

Figure 9 - Image showing air, environment and globe temperature.

Once you understand that the temperature graph shows environment temperature, things should start to make more sense. Such a temperature tells you much more about how a person is likely to feel inside that space than air temperature alone.

Bounce-Back

As the Admittance Method is based on variations about a mean temperature, very large changes in loads can result in what is known as bounce-back or 'springiness'. If you think of the internal temperature as an elastic spring, if you give it a good tweak in one direction it will bounce back almost as far in the opposite direction.

[**Insert Image Here**]

Figure 10 - Graph showing bounce-back effect.

For example, if you modelled a glass walled sunspace or conservatory and it received very high solar radiation during the day, this will result in peak temperatures much higher than corresponding outside air temperatures. Similarly, if you looked at the graph at night, you will probably see internal temperatures falling below nightime outside air temperature.

We could obviously explain this away by saying that such a warm day was likely to have had little cloud cover so that, when the still-hot internal surfaces were exposed to a clear night sky (at an effective radiatant temperature of something like -260degC), the glass re-radiated sufficient heat back to the night sky to produce the lower temperatures. Whilst certainly a valid and highly-likely explanation, this is probably also part rationalisation of an effect produced by the algorithm itself.

Convection and Complex Air Flow

[**Explain trombe walls, etc.**]

ABSOLUTE VS RELATIVE ACCURACY

It is important to note that, in many cases, the absolute accuracy of a calculation result is often not that important at the earliest stages of design, as long as the basis of any comparative calculations are the same and that relative accuracy is maintained. Thus, using a very simple geometric model you certainly wouldn't guarantee that the total thermal gain at 5:15pm on Friday the 15th of April in the finished building will be exactly 867.2W. However you could be reasonably sure that the design option with the larger window, which increased solar heat gains at that time and date by about 15%, would have a similarly proportional effect in the real building.

The absolute accuracy of calculated results obviously increases as the design develops and greater model detail is added. However the relative calculations carried out very early on will usually be by far the most influential in the final design.

The greatest benefit of the Admittance Method is when it is used as a **comparative tool** - when comparing the relative impacts of a range of different design options. This way, many of the potential inaccuracies due to simplifications and assumptions within the simulation method are countered by the fact that they are present in each of the compared models. Any differences between the two results must be due to variations in the fundamental characteristics that the simulation method models, so if you understand those aspects of the simulation method, then this in itself can help you better grasp how the two building models work.

This concept of relative accuracy is also explored in the Comparing Thermal Results article.

CONCLUSION

The Admittance method is a very powerful and insightful thermal analysis technique. It is fast and scaleable to any geometry, which makes it very useful to the designer especially at the earliest stages of design. However, it is only one of many different thermal simulation methods. Whilst no single method yet devised is perfect, there are others such as the Finite Difference and Response Factor methods that are more comprehensive in the characteristics they deal with and more sophisticated in the mathematical modelling involved (though not necessarily more accurate in many situations).

Ecotect's internal thermal analysis functions are best used as a comparative design tool. In keeping with this idea, if you do need to perform very accurate thermal analysis, you should really export your model to a couple of different simulation engines as you will find that they will each produce a slightly different result. No single tool will ever give you exactly the right answer. However, if several tools agree within a relatively small range, then you can be reasonably confident that the results are usefully indicative. If their results vary quite significantly, then it is likely that the simple act of tracking down why this is the case will teach you a huge amount about how your building is likely to perform, even if you never actually get the results to agree.

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