The dead state of buildings

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Abstract:
Exergy is typically defined as the maximum work that can be extracted from a system when reaching equilibrium with its "reference environment" - a large region unaffected by the interactions - and derives from Gibbs' original concept of "available energy of a body and medium". The reference environment definition plays a key role in exergy analysis but is still controversial, especially in the case of buildings; the most popular choice is the local outdoor air, because readily available and largely unaffected by the presence of the building, but its fluctuating conditions pose various challenges. The controversy around the reference environment arguably remains one of the main blockers in the practical application of building exergy methods. However, going back to the origins, Gibbs defined available energy not only for a "body and medium", but also for the case of a "body alone", a system formed by subsystems in non-equilibrium conditions. Later, exergy too was defined for this second case, as the subsystem contribution to the body available energy. In the case of the "body alone", the reference is the "dead state" (the thermostatic condition of the body), in place of the reference environment. The main idea of this article is that building exergy analysis can be based not only, as currently, on the exergy definion originated by Gibbs' case of the "body and medium", but alternatively on the exergy definition originated by the case of the "body alone", for which a large environment is not needed. The outdoor reference environment can thus be substituted by an indoor "dead state". The study discusses possible system boundaries and ways of defining the building dead state based on indoor conditions, and the potential impact on building exergy analysis. The dynamic exergy modelling of a few cases is presented to visualise the numerical implications.

Keywords: Exergy, reference environment, dynamic analysis.

1. Introduction

Debating the reference of exergy analysis requires going back to the beginning, and investigating where its requirements originated. Gibbs [1873] was the first to combine the first and second law of thermodynamics in one equation [Klein, 1990], in his first paper "Graphical methods in the Thermodynamics of Fluids". The combination of the first and second law of thermodynamics led Gibbs to introduce the concept of "available energy"; he distinguished two cases: a "body alone", in internal non-equilibrium conditions, and a "body and medium", in non-equilibrium conditions with each other.

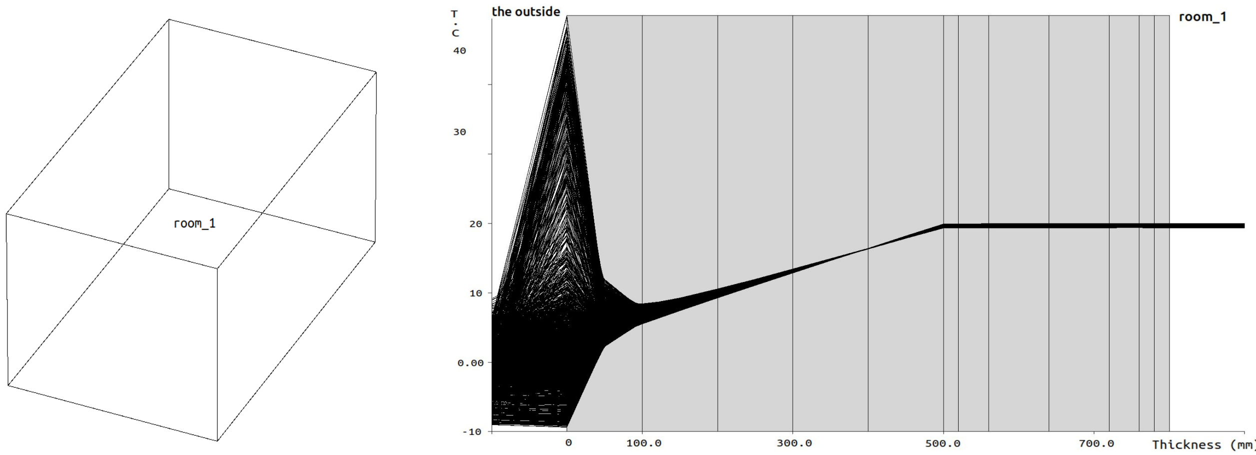
In the case of the "body alone", the available energy of the body is the greatest amount of mechanical work that ideally can be obtained by taking the body, without any net contributions of energy from external objects, from its initial non-equilibrium condition to the point of stable or neutral equilibrium (on the "surface of dissipated energy") that has the same entropy and volume of the initial state. The internal non-equilibrium state of the body can assume various forms, like a difference in the pressure of some of its part, or a gradient in temperature, or even different chemical compositions. It is important to observe that the term "body" refers not necessarily to a single entity but to a system potentially including several subsystems and processes [Gaggioli, 2012].

In the case of the "body and medium", the medium is supposed to be at constant pressure and constant temperature. The medium is also called "reference environment", a large subsystem that is not affected by the interactions with the other components of the overall system, and it is represented by a plane in Gibbs' graphical representation of the energy-entropy-volume space. The available energy in this case is the distance (on the energy axis) from the point corresponding to the initial conditions of the body to the point on the medium plane with the same entropy and volume. Even if the body is in internal equilibrium, the combination between body and medium can still have available energy, unless they are in the same conditions.

Gaggioli [2012] provided a definition of the "dead state" based on Gibbs' "available energy of a body" (the first case mentioned above) that does not require a reference environment.

2. The dead state of a very simple building

Discuss an insulated cave with no air exchanges and negligible internal gains. Simulate it on the side and present image.



(a) ESP-r box model.

(b) Cumulative values of intra-construction temperatures in a wall of the box model.

Figure 1: The first case study: a box model with 500 mm of exterior insulation and 300 mm of earth on the internal layers.

3. A more realistic case

Statement about the importance of internal loads, not only for summer but also on heating strategies. Include window and internal gains. Simulate on the side and present image. Still very good insulation. Also present increasingly complex cases, with air exchanges and lower insulation, mainly visually. Define the "core" of the envelope (periodic penetration depth) and specify that it is a first attempt definition.

Calculate instantaneous dead state and compare with target dead state. Do a sensitivity analysis of typical quantities involved.

4. Dead state and design goals

In most cases the core of the building envelope is far from an isolated system, but the indoor environment has a comfort target nevertheless. When the HVAC system is switched off, we expect the indoor conditions to remain comfortable for as long as possible, and as soon as they fall out of an acceptable range the heating or cooling system intervenes again to bring temperature and sometimes also relative humidity back to the required values. In other words, it is like if the composition of the overall system changed dynamically to include subsystems capable of re-establishing the desired dead state. Sometimes the external environment has the exergy that the building needs to maintain its conditions, for instance cooler air could be let in to readdress internal gains, or solar radiation could enter from fenestration to compensate transmission losses. When the balance cannot be maintained by passive design strategies, an exergy input from renewable or non-renewable sources is required. In any case, the final destination is an indoor environment very close to, or going towards, comfort conditions, with a multitude of exergy fluxes and storages being orchestrated to balance each other with the goal of a comfortable dead state.

The core of the building, including the internal part of the envelope and the indoor environment, might have both warm and cool exergy storages, which both contribute to the overall exergy, in this case also "available energy". A greater available energy is an expression of disequilibrium, and potentially of a greater effort needed to maintain comfort conditions. Zero available energy indicates that the system is in uniform comfort conditions, because all the exergy contributions are positive.

5. Conclusions and future work

Wall insulation is relatively easy - main challenges today are indoor comfort and thermal storage / decoupling energy demand and offer (just my opinion though, look for references). Indoor dead state shifts the focus on the indoor environment.

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