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Technical note

Robustness of buildings and HVAC systems as a hypothetical construct explaining differences in building related health and comfort symptoms and complaint rates

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Abstract

In statistics, the ability of a certain technique to deliver accurate results, although its assumptions are violated, is called the robustness of that technique. Analogously, the robustness of an (office) building or an HVAC system can be defined as the measure by which the building or the system lives up to its design purpose in a real life situation. Lack of robustness can be caused by hypersensitivity to aberration from the design assumptions, unfeasible maintenance demands, integration of heating and ventilation, regulating supply air volumes and lack of transparency to occupants and buildings management. The robustness hypothesis helps explain the results of field studies and mitigation investigations and has enough scientific credibility to warrant further research. It turns out that source control may be viewed as a special case of robustness. The concept of robustness has important ramifications for design practice and is totally in sync with recent developments in indoor environmental research.

Keywords: Building physics; HVAC design; Guidelines; Standards; Source control; Thermal comfort; Sick Building Syndrome

1. Introduction

Epidemiological studies consistently show that occupants' complaints are more prevalent in office buildings with more complex HVAC systems, that is systems with more technological devices to control and regulate the indoor environment. These complaints not only include physical symptoms [1,2], but also complaints about indoor air quality and thermal comfort [3,4]. Since in most cases these more complex systems primarily aim at better compliance with some set of health and comfort standards, the higher complaint levels seem odd. The most frequent explanation of this phenomenon is that more complex HVAC systems contain more potential sources of indoor air pollution, like filter sections, cooling sections and humidifiers. The authors of this paper submit that this, though in itself correct, is only part of the explanation, and that a more comprehensive explanation can be hypothesised.

2. Robustness of statistical techniques as a paradigm

The starting point for a more comprehensive explanation is the realisation that what we have here is a discrepancy between a high level of performance of some technologies on the drawing board and in the test chamber and an unexpectedly low performance of the same technologies in real life situations. Moreover, this discrepancy is not the same in all cases. Less complex HVAC systems, especially when combined with adequate building physics, seem to live up better to the expectations occupants have of them. This discrepancy between performance in theory and performance in practice draws attention to an analogous situation in another discipline, namely statistics. Statistical techniques to estimate parameters or to test hypotheses often assume very specific mathematical assumptions to be true. The most common assumption probably is that variables are normally distributed. These assumptions are seldom met in research practice. This would of course be a great problem if violation of the assumptions would in all cases lead to invalid conclusions. Fortunately, this is not the case. It turns out that some statistical techniques are rather insensitive to violations of their assumptions, while others are very

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sensitive. In statistics the ability of a certain technique to deliver accurate results although its assumptions are violated is called the robustness of that technique. To statisticians this is obviously an important measure because when in a certain experiment the statistical assumptions are not met one would prefer a less sophisticated but more robust technique to a more sophisticated but less robust one [5].

3. Robustness of buildings and HVAC systems

Analogously, the robustness of an office building and an HVAC system can be defined as the measure by which the building or the system lives up to its design purpose in a real life situation. It is the authors' belief that many designs that function flawlessly on the drawing board and in the test chamber systematically function less well when they perform in an operating office. This may be so for one or more of the following reasons:

3.1. Sensitivity to aberrations from design assumptions

Some designs are overly sensitive to (small) aberrations from the design assumptions. An example is induction-units. With induction-units it is very important that the properties of the units, like air volume, temperature, type of nozzles and supply air grids, are closely matched to the properties of the room, like geometry, location of windows and internal and external heat load. A mismatch will result in a disruption of the flow pattern and consequently in too high air velocities in the occupancy zone. It is the authors' experience that in practice such mismatches frequently occur. If during the building process a different grid is selected or a different ceiling structure is opted for, as can easily happen, the flow pattern will be disrupted. Technically simpler heating and ventilation systems are far less sensitive to these sort of changes and are therefore more robust.

Another example are air supply grids in the floor of work spaces. Since air velocities near these grids will likely exceed comfort standards, the grids must be placed at a suitable distance from places where occupants may dwell. This requires that the floor plan of the grids is matched to the layout of the workstations and the traffic zones. But if the layout of the workspace needs to be changed, e.g. for organisational reasons, the grids may be too close to the occupants, resulting in comfort problems. A system with air supply grids in the ceiling will allow much more changes in the layout and is therefore more robust.

3.2. Unfeasible maintenance requirements

Some designs require more maintenance than others. To contrast two extremes: increasing heat accumulating building mass, e.g. installing thermally open ceilings, to limit temperature transgressions by free cooling is very a robust measure. Once properly installed hardly any maintenance is required. Another robust measure is reducing window area. On the other hand a cooling section and for instance variable air volume-units require recurrent maintenance. Particularly high demands on maintenance are set by devices where humidity can cause microbial growth, such as spray humidifiers. Such devices lower the robustness of the system. Robustness is lowered even further by devices such as the drip trays of induction-units which may be micro-biologically contaminated. These are distributed all over the building, which significantly lowers the probability that they are all maintained properly. This may help explain why [6] a field study of 16 German office buildings found that approximately one third of the investigated non-induction systems were properly maintained but that of the induction systems, also amply available in the sample, none were properly maintained. Generally speaking, measures that optimise building physics require less maintenance and are therefore more robust than more elaborate HVAC systems and centralised systems are more robust than decentralised systems.

3.3. Integration of heating and ventilation

When heating and ventilation are in some way integrated, they appear to be more prone to malfunctioning than systems where heating and ventilation are separated as much as possible. One example are induction units where decreasing the air supply, e.g. to prevent draught or noise, may also decrease heating or cooling capacity. Another example are VAV units, where regulating the air supply in order to keep the indoor temperature constant may led to insufficient supply air volumes (see the next heading).

3.4. Regulating supply air volumes

One of the significant results of the European IAQ Audit [7] was that in systems with recirculation of the exhaust air the actual amount of recirculated air was in most cases significantly higher or lower than the specified amount. This not only underlines the risks of recirculation, it also is a reminder that in practice supply air volumes may not be regulated as accurately as we may like to think. In other words, regulating supply air volumes lowers robustness. This is especially so in the case of variable air volume-systems where the air volume control devices are distributed all over the building so that adequate control and maintenance are hardly feasible. Of course in the case of variable air volume-systems the air volumes are regulated in order to control room temperature, so this is also a case of integrating heating and ventilation, as discussed under the previous heading.

3.5. Lack of transparency to occupants and building management

An HVAC system is transparent when (relative) laymen can gather some basic understanding about the working of the system just by looking at it and using it and when they also can perceive that the system is not functioning well and, up to a certain level, what is wrong with it. Some examples: