

The AUDITAC Customer Advising Tool (CAT) to assist the Inspection and Audit of Air Conditioning Systems in Buildings

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SUMMARY

This paper describes the production of the Customer Advising Tool (CAT), a piece of software to help assess the potential for reducing the cooling demand of Office buildings, as required by Article 9 of the EPBD. It is a practical tool aimed at use by building owners, inspectors and auditors as part of the Inspection and Audit process. The tool was developed by the authors as part of the IEE AUDITAC project.

The tool is based on a mixture of monitored and modelled data, and this paper presents the tool's development, concluding with how the inputs and outputs are simplified down to those required to provide a focus to the on-site inspection and audit.

It is anticipated that many Member States will refer to the tool as part of their support for implementing Article 9. The tool can be downloaded from, or used at, the following website: http://www.cardiff.ac.uk/archi/research/auditac/advice_tool.html

INTRODUCTION

Article 9 of the European Energy Performance of Buildings Directive (EPBD) is concerned with reducing the energy consumption of Air Conditioning systems in buildings. The second paragraph of Article 9 states *“This inspection shall include an assessment of the air-conditioning efficiency and the sizing compared to the cooling requirements of the building. Appropriate advice shall be provided to the users on possible improvement or replacement of the air-conditioning system and on alternative solutions”*.

The practical reality for the auditor/assessor in meeting Article 9 is that they have a limited timescale in which to assess/estimate the performance of both a building and its A/C systems. Within this timescale it is likely that the assessment of the A/C systems will occupy the majority of the time. A quick and easy method of assessing the effect that the building and its usage is having on the A/C system cooling demand is therefore required to minimise the time and effort spent on this task.

The purpose of this paper is to provide details of the recently published AUDITAC Customer Advising Tool (CAT) [1]. This tool has been designed to provide information, in a form accessible to a building owner or assessor, on which aspects of the Building Fabric and Operation are likely to be having the largest effect on the cooling energy demand imposed on

the building's Air Conditioning systems, and therefore which areas are most likely to provide the greatest potential for reducing this demand. The tool also provides an indication of the percentage change in cooling demand that would occur through variation of aspects of the building design or operation. It is important to note that the tool is a **holistic** design tool, i.e. it considers the overall cooling demand resulting from the **interactions** between all the criteria and parameters specified.

It is important to note that the CAT has been derived using data from Offices, but it is believed that the basic findings should be generally applicable to any situation that matches those described in the CAT input sections.

The nature of cooling demands in buildings

Modeling, monitoring and other studies on cooling in buildings and building services by the authors [2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17] and other researchers, have shown that those factors which have a significant effect on a building's heating and cooling demands are relatively few.

The heat transfer mechanisms within buildings are the familiar ones of radiation, convection and conduction. These mechanisms will transfer energy into or out of a building depending on the following main factors:

- Time of day, week, year.
- Ambient weather conditions.
- Design of the building, its services, and its location with respect to overshadowing, exposure, etc.
- Building use, i.e. occupancy type, hours of use, layout.
- Internal conditions provided in the building.
- Effectiveness of building services controls

The CAT considers these aspects in terms of their effects on the cooling demand of buildings. The data presented by the CAT is obtained purely from modeling, but the results have been compared with previous measurements and monitoring to provide a few points of reference. The CAT presents the findings from the work in a manner that is of use to the assessor in meeting the requirements of Article 9.

The design of the CAT uses the extensive experience of the authors in assessing the energy performance of buildings and A/C systems to minimise the information an assessor needs to obtain to use the tool. It does this by asking only for information that can be used to estimate, and make improvements to, the building cooling demand.

Within the context of the CAT, the factors noted above which affect the cooling and heating demand in buildings can therefore be simplified into various criteria and parameters that the assessor can establish for each building.

Not all of the criteria and parameters identified as important were able to be assessed through modeling, primarily due to time and resource constraints. Details are given later in this paper. The other limitation of the CAT is that it has not been possible to model all the possible permutations of the criteria and parameters. This is again due to the impossibility of achieving this in the time with the computing resources available. Therefore the CAT modeling has used a technique of varying some of the individual **parameters** around an **average** value that is

considered by the authors to represent the best compromise of all the possibilities available for that parameter. Nearly all the possible permutations of the **criteria** assessed have been modeled however.

Use of the Customer Advising Tool

The authors consider that the CAT will be used primarily at the pre-audit stage of an inspection. At this stage the CAT can usefully identify the main aspects of the building and its operation which might be further studied onsite by the assessor in their search for potential means in reducing the building cooling demand.

While the CAT cannot consider the detail of the individual buildings to be inspected, its ability to holistically consider the interaction of some of the main contributors to building cooling demands is a major assistance in writing Inspection Reports.

DETAILS OF THE PARAMETERS AND CRITERIA USED IN THE CAT MODELING

The basis of the CAT modeling is an open-plan cube of dimensions 10m x 10m x 2.4m. This cube is shown in Figure 1 as part of a 9 cube square. Once each layout is generated, inter-zonal adjacencies between each cell are calculated, making it possible to discern for each side whether it is adjacent to another cell or exposed to external conditions. Windows of the appropriate size are then automatically inserted into each exposed facade element.

The apparently low ceiling height reflects the authors' desire to approximately model the effect of occupancy on the reduction of internal volume in the space (taken as about 20%), and hence the reduction in ventilation air needed to achieve the required air change rate.

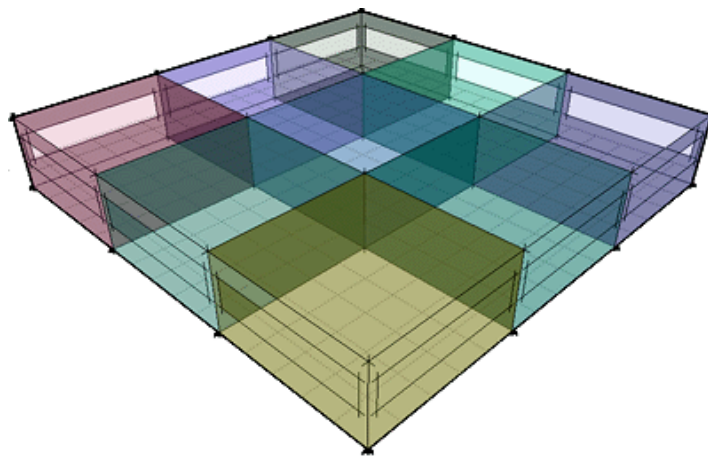


Figure 1. Basic cube model, shown as the deep plan 30m x 30m layout.

The various combinations of the basic cubes and their properties were modeled in the ECOTECH software programme [18] and exported to the EnergyPlus building energy modeling software [19] to be run with the various combinations of criteria and parameters required to meet the purposes of the CAT.

Descriptions of the individual criteria and parameters modeled which are applied to the permutations of this basic cell model are discussed in more detail below, along with the ranges over which each criteria or parameter was modeled. The descriptions also consider how an assessor might go about classifying each for a building.

CAT criteria

For the CAT, **criteria** are deemed to be those elements of the building design or operation that are known to have an influence on the heating and cooling demands, but are realistically unlikely to be altered simply to try and reduce heating and cooling demands.

Plan depth: The ratio of floor area to total external facade area. A shallow plan will normally allow daylight and natural ventilation to be used over the entire floor area. A deep plan will usually be fully mechanically ventilated. The choices available and modeled for this criterion are shallow plan (10m x 10m); medium plan (20m x 20m); and deep plan (30m x 30m)

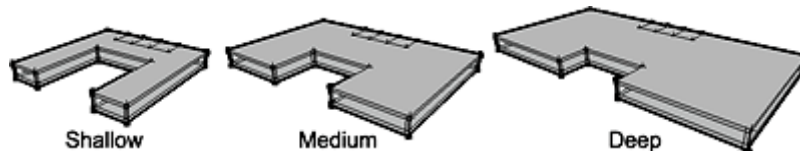


Figure 2 - Three options for characterising plan depth.

Glazing ratio: The glazing ratio represents the percentage of the exposed external vertical facade area of the building that is considered to be a solar aperture. This is typically a glazed area having some transparency to both visible light and solar radiation. Variations in glazing ratio were modeled using windows of the same sill and height but with different widths relative to each wall surface such that the ratio of glazed area to total vertical facade area represented 20%, 40%, 60%, 80% and 90%.



Figure 3 - Values for characterising facade glazing ratio.

Thermal mass: In order to consider the effect of thermal inertia on building performance, it is necessary to define this criterion which is based on the amount of internally exposed thermal mass. A building with significant amounts of masonry or concrete visible would usually be classed as heavyweight, whilst a building which is predominantly suspended ceilings and lightweight partition walls would usually be classed as lightweight. The choices available and modeled for this criterion are lightweight, mediumweight and heavyweight.

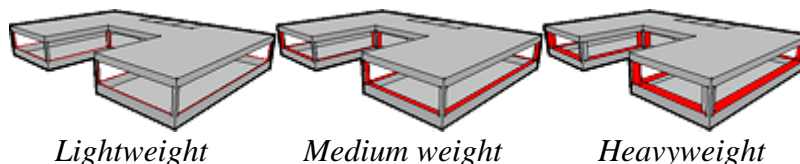


Figure 4 - Three levels of internally exposed thermal mass.

Weather locations: The city location/region modeled by the CAT which is most likely to reflect the weather conditions to which the audit building will be subjected. Regional variations in climate were considered by using average annual weather data sets for a range of locations throughout Europe in the calculations. The choices available and modeled for this criterion are Vienna (Austria), Berlin (Germany), Madrid (Spain), Paris (France), London (UK), Athens (Greece), Rome (Italy), Lisbon (Portugal) and Stockholm (Sweden). These were modeled to allow a choice of climatic zones.

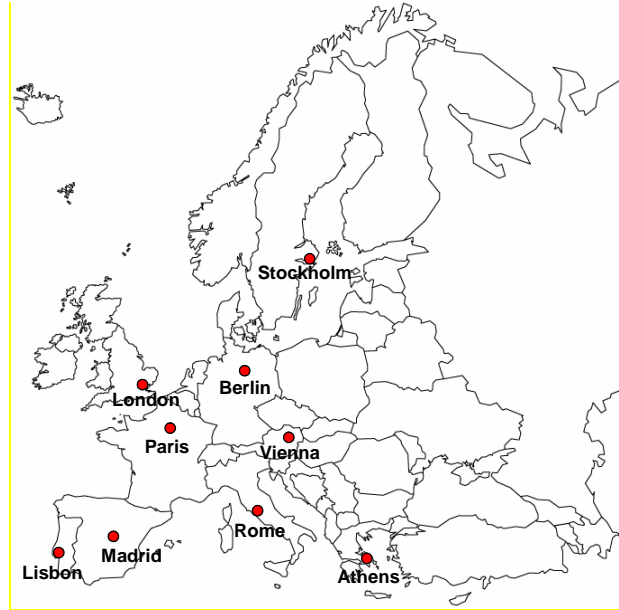


Figure 5 – Map of European weather locations modeled in the CAT.

Internal layout: This reflects whether the building is predominantly cellular offices or open plan. *The CAT currently considers the building to be comprised of 10m x 10m open-plan cells as noted earlier. These options are not available in the model yet.*

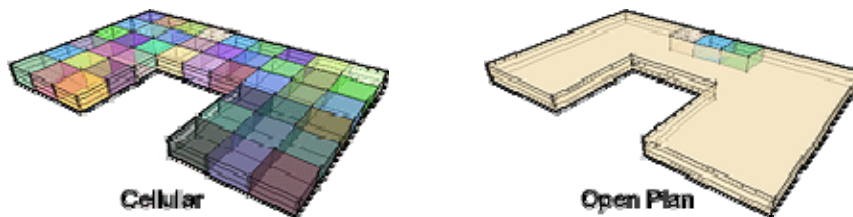


Figure 6 – The two extremes of internal layout.

Building form: This reflects the effect of building form on issues such as self-shading and ventilation rates. *Only the square form has been modeled for this criterion.*

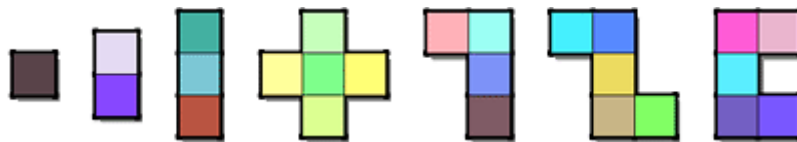


Figure 7 – Examples of simple cell layouts.

Multiple storeys: Due to the number of runs involved, work to include the effects of multiple storeys has not yet been included in the CAT. However, the strategy to do so has been carefully considered. To represent buildings with any number of storeys, it is necessary to simulate ground floors (which may be underground or in direct contact with foundations) separate from top floors (which may have an exposed roof or be in direct with a ventilated plant room directly above) separately from mid-level floors (for which thermal transfer through the floors and ceilings is likely to be negligible).

Moreover, self shading of windows on lower floors may be quite pronounced in some of the plan layouts making it necessary to model the floors above. Whilst it would be possible to generate and test a series of multi-storey versions of each plan layout, as shown in Figure 8, the resulting number of runs becomes prohibitive.

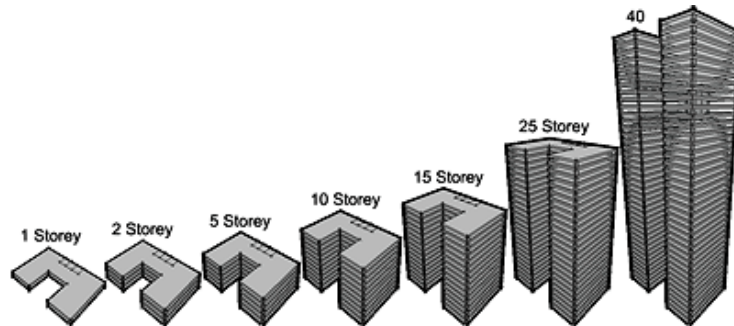


Figure 8 - Simulations should allow choice of any number of storeys.

A proposed solution was to generate 3 models for each plan layout. The first, representing a top storey, would be assigned an adiabatic floor (to simulate insignificant heat flow to the zones below) and an exposed roof. The second, representing a mid-level storey, would be assigned both an adiabatic floor and an adiabatic ceiling (to simulate insignificant heat flow to zones both above and below) with an additional non-thermal zone generated above to simulate any self-shading effects. The third model, representing the ground storey, would be assigned a ground-connected floor and an adiabatic ceiling, as well as a much larger non-thermal zone above. The different models are illustrated in Figure 9 below.

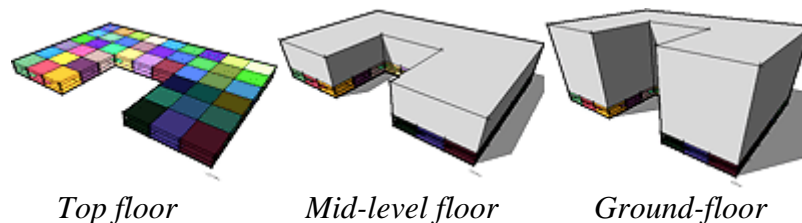


Figure 9 - The three models required to simulate multi-storeys

This way, by simply performing three runs, it is possible to represent any number of storeys by adding the energy demand of the ground and top floors to a number of mid-level floors equal to [storeys-2]. This assumes that the self shading effect on the mid-level floor represents the average over all floors. Figure 10 illustrates the theoretical assembly of this building.

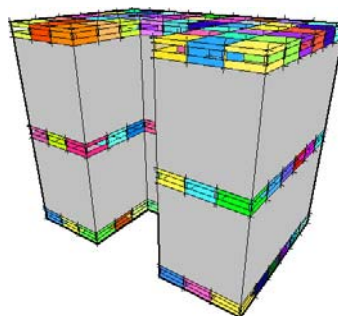


Figure 10 - Assembling a multi-storey building from the 3 models.

Single storey buildings, with both an exposed ceiling and a ground-connected floor must be represented by an additional and separate fourth run based on a model with both a ground-connected floor and an exposed ceiling. *Only this single storey building has been modeled for this criterion in the CAT to date.*

CAT Parameters

Parameters are defined as those elements of the building design or operation that are known to have an influence on the heating and cooling demands, and are potentially able to be altered by the assessor or building owner.

Fabric U-value: This refers to the overall surface-averaged thermal conductance of the opaque elements in the external building envelope. This includes the roof as well as facades. The effects of this parameter have been modeled between 0.1 and 4.0 W/m²K. The average value used for this parameter is 0.5 W/m²K.

Window U-value: This refers to the overall surface-averaged thermal conductance of the windows and transparent elements in the external building envelope. The effects of this parameter have been modeled between 0.5 and 6.0 W/m²K, where the most insulating transparent element available would have a U-value of around 0.5 and single glazing would have a U-value of around 6.0. The average value used for this parameter is 3.0 W/m²K.

Solar Heat Gain Coefficient (SHGC): This is the fraction of incident beam (direct) solar radiation that enters the building through the transparent elements, such as windows. This includes the transmitted solar radiation and the inward flowing heat from the solar radiation that is absorbed by the glazing. The effects of this parameter have been modeled for SHGC's ranging from 0.1 to 0.9, where 0.1 is highly shaded, (i.e. little solar gain), and 0.9 means no effective shading. The reduction from 1.0 is simply due to the normal properties of glass. The average value used for this parameter is 0.5.

Air change rate (infiltration only): This refers to the uncontrolled exchange of air between internal spaces and outside air due to gaps in the building fabric linked to design details. This value is given as the number of complete air changes per hour. The effects of this parameter have been modeled between 0.1 and 4.0 ac/hr, where a well detailed, well-sealed building would be around 0.1 and a very leaky, shallow plan building in an exposed and windy location would be around 4.0 ac/hr. The average value used for this parameter is 0.5 ac/hr.

The tool does not specifically include a parameter for varying the **ventilation** air change rates, as it was deemed that this would be set by the building owner to meet the ventilation and cooling demands of the building. However, in tightly sealed buildings, the effects of modifying the ventilation rate can be approximated by adding the infiltration and ventilation rates together. This sensitivity analysis could be useful if a change from using air as the heating and cooling transport medium to recirculation A/C systems with separate fresh air supply were being considered.

Internal Gains (W/m²): This refers to the contribution of small power, lighting and people loads per metre squared floor area. The effects of this parameter have been modeled between 10 and 160 W/m², where 10 W/m² represents a very low density of occupation and equipment use, and 160 W/m² would represent a very high density of equipment and occupancy, such as a business call centre. The average value used for this parameter is 40 W/m².

Hours of use of the heating and cooling systems: This parameter refers to the effect of running the systems continuously or over the working week only (assumed 08:00 to 18:00 in this system). *The effects of optimum start/stop have not been assessed.*

Variation in heating and cooling setpoints: The CAT assumes a heating setpoint of 21°C and allows the cooling setpoint to be varied between 21 to 25°C in 1°C intervals. *It does not allow the effect of varying the heating setpoints to be assessed.*

Variation in occupancy, equipment and lighting schedules: This parameter refers to the effect of intermittent or continuous occupation, equipment or lighting schedules. The CAT assumes an 08:00 to 18:00 schedule for all these parameters including the HVAC equipment. *The effects of various combinations of continuous and intermittent schedules of these parameters have not been assessed.*

Spatial distribution of cooling loads: This reflects the possibility of moving the cooling loads within the space to minimize the cooling demands on the A/C system. *Only evenly distributed loads are currently considered by the CAT.*

System Parameters

In order to accurately compare heating and cooling energy, as well as calculating potential carbon emissions savings, the relative efficiency of the plant and equipment used to supply the building's heating and cooling demand must be specified or estimated. These values are usually very difficult to obtain with any accuracy so it is necessary to test the likely range in the building being assessed to estimate the sensitivity of any recommendations to reasonable variations in these figures. These are defined in this work as *system parameters* and include the following for both the heating and cooling systems if present in the building.

Heating System Efficiency (SCOP)

This defines the Seasonal Coefficient Of Performance (SCOP) for the equipment used to provide space heating within the building. This is given as the annual average ratio of total heat output compared to total energy input to the equipment. A good condensing boiler based system would expect to achieve a SCOP of around 0.9, whereas an old cast-iron boiler based system might struggle to reach 0.6.

Cooling System Overall Efficiency:

This is the overall annual ratio of the cooling energy demand met by the installed cooling system, divided by the total energy input to the cooling system. It includes auxiliary energy consumption as well as the chiller energy consumption. It is important to note that this is NOT the Energy Efficiency Ratio (EER) for the equipment used to provide comfort cooling within the building. A low rating (0.3 - 0.6) would apply to an inefficient system, and a high rating (>2.0) to an efficient system. An average performance is likely to be 1.0 - 1.5.

Countries with high cooling demands are likely to see better overall efficiencies than countries with low cooling demands, as the chiller energy demand in hot countries will be a greater proportion of the overall cooling system energy consumption.

Fuel Carbon Emission Factor

The amount of carbon dioxide emitted through the consumption of 1 kilo-Watt hour of fuel used. This is given as a value between 0.0 for totally renewable energy and 0.43 kgCO₂/kWh for delivered grid electricity - although allowance is made in the CAT for values up to 0.60.

For countries other than the UK the appropriate Grid delivered electricity factor should be used. Refer to the International Energy Agency (<http://www.iea.org>) for further information.

DISCUSSION

Interpreting the outputs from the cat

Once the building assessor has entered values for each of the above criteria and parameters (or accepted the default values offered) the CAT then searches its database to find the output graphs that match these values.

Figure 11 shows an example output graph.

Output graphs present the PERCENTAGE change in heating and cooling demands that would occur for a given change in an individual parameter, along with an estimated overall change in carbon emissions. The value assigned to each parameter is shown by the vertical green line on each graph, and the percentage changes in the Y-axis are relative to this value.

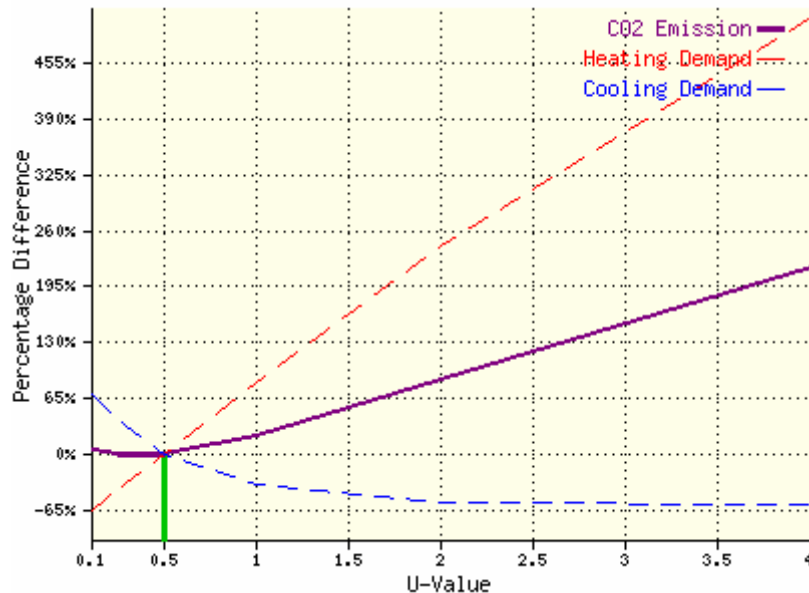


Figure 11. Example output graph showing the percentage change in heating and cooling demand achievable by varying the building fabric U-value from the input value (0.5).

A positive percentage increase shows an increasing demand for heating or cooling, and increasing carbon emissions. A negative percentage shows a reduction in these values.

The carbon emissions line is used as a proxy for assessing whether the proposed parameter changes might adversely affect the heating demands. The carbon emissions estimates are derived using the heating and cooling system parameters entered on the input screens, so it is important these are as accurate as possible, but they are still only estimates as the values entered will vary with time of year and actual demands on the systems.

In this example the graph shows that from a carbon viewpoint the current fabric U-value is probably the optimum for the combination of criteria and parameters chosen. Had we increased the U-value to 2.0 then from the graph we would have potentially achieved around a 60% reduction in the cooling demand, but the heating demand would have risen 250% and the overall carbon emissions around 100%.

The assessor would therefore not need to consider this as a potential area for improvement in the on site survey. This graph also shows the importance of considering the building and occupancy holistically. Had the heating impact not been considered then it would have appeared that we would need a less insulating U-value than currently installed.

The output graphs are viewable as both annual and monthly graphs for each parameter, so that the seasonal variation of the loads due to a given parameter can be assessed. At present the CAT does not allow the assessment of dynamic parameter changes in one run, e.g. using moveable shading to alter the SHGC only through the months requiring cooling. However the assessor can run a series of different parameter values which would give him the same information.

CONCLUSION

This paper has provided an overview of the derivation of the CAT, a tool which shows how a building's basic design and operation might affect the cooling demands placed on an A/C system used in the building, and how these demands might potentially be reduced through altering aspects of the buildings design or operational parameters.

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The sole responsibility for the content of this paper lies with the authors. It does not represent the opinion of the European Communities. The European Commission is not responsible for any use that may be made of the information contained therein.

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