Prediction of the thermal behaviour of an office building using TRNSYS with proposal and evaluation of improvement actions

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Abstract.

The most important decisions that affect the thermal behaviour of buildings are taken in the initial stages of design. Design evaluation may be supported by the results of building simulation. The aim of this paper is to predict the thermal behaviour of an office building with TRNSYS and to propose architectonical and management improvement actions. These improvements are formulated to solve one design problem of this building. The results shows that models in TRNSYS are a good system to simulate the reality and they can represent the different scenarios to evaluate energy and economic savings in short period of time and without spend the money. The best solutions are the ones who are tough for the all year with all the conditions, analyzing the life cycle and the savings in a medium-long period of time; it can reach an energy saving of 33%. The calculations show that it's possible to reduce 33% of cooling energy with free-cooling ventilation and an energy saving of 20% increasing 1ºC the comfort temperature during summer.

Keywords

Temperature predictions, TRNSYS, Building behavior; Building simulation.

1. Introduction

Buildings in most countries around the world require large amounts of energy both for cooling and heating. Building simulation, from the point of view of calculating energy consumption for heating and/or cooling of buildings, has been of much interest in recent years [1,2].

ParcBit is a public project placed in Palma with the aim of serving as a platform for the implantation and development of the information society in the Balearic Islands. The energy of the buildings in the Park is provided by a tri-generation plant which is placed over there. It has two diesel motors 2,9Mw, a solar thermal installation of 864m^2 and some photovoltaic panels of 8,6kwp. ParcBit takes steps for environment such us to control and to minimize the demand of buildings' energy [3,7].

The first building, Fig. 1, named Building 17 was made at the end of the year 2001 and it was found that it wasn't possible to maintain the comfort conditions in the offices during summer 2002. The problem was related to the fact that the orientation of the building differed from the specified in the initial project, hence the design of the NE façade of the building occasioned that the offices reach high temperatures. In summer 2003 one fixed curtain in NE façade was installed as an urgent solution. Thus a 70% of the incident solar radiation was blocked. Later, during 2004, an accurate study including TRNSYS [4] simulations and experimental measures was carried out. The aim of this paper is to present the numerical and experimental results as well as the evaluation of several solutions for the comfort problem.

A meteorological station was installed on the roof of the building in order to know the environmental conditions for the simulations and to predict the temperature for one office in the building.

Fig.1 Building 17

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2. Building 17 and the model in TRNSYS

The Building 17 is like a rectangular block which is oriented 39º east, see Fig. 2. It has four floors with different office modules with a 3961 m^2 of total surface of the offices.

Fig. 2. Orientation of Building 17.

According to the fourth article of the Basic Building Norms, NBE-CT-79, the global heat transmissions through the façade walls, which are given by K_G coefficient, it can't be higher than a determinate value depending of the form factor *f*, the climate zone and the source energy used to acclimatize the building. For the Building 17 the K_G coefficient can't higher than 1.47 but the really value of K_G coefficient is 1.70. The initial K_G was 0.965, that value was calculated in the architectonical project without know the exactly properties of the materials. So the calculus shows that this building is not according to the norms.

One important question is the configuration of the NE façade. This façade has a 145 m^2 of glass block in the ground floor, and in the other floors it has a 692 m^2 of U-glass and armed glass, both separated 18.5 cm, Fig. 3. This configuration causes a high heater in the air between the two glasses and causes a transport of heat by convection between two glasses. So the armed glass is heated and causes a higher temperature in the office.

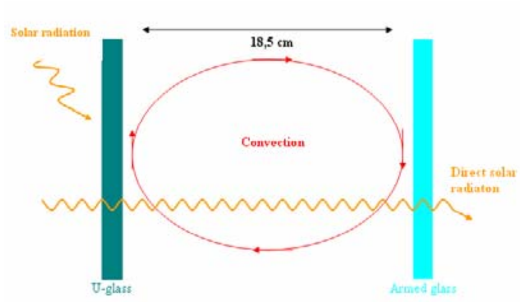

Fig. 3. Configuration of NE façade. Heat transfer by convection.

To have a grate study a model in TRNSYS has been. That model consists in 19 zones. The one number 19 (the prove office) corresponds to an office placed in the second floor which was installed one measure equipment formed by nine thermometers and one humidity meter, Fig. 3 shows the places of these measures meters. The building is simulated with real conditions for all zones. All material properties were introduced in the model from the architectonical project and some inspections in situ of the building.

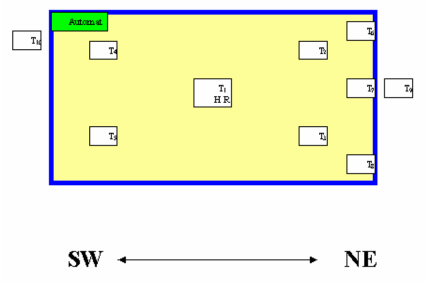

Fig. 3. The prove office

In the aim to know the environmental conditions one KRONOS meteorological station was installed on the roof of the building. The sensors of this station are: thermometer, humidity meter, rain meter, radiometer, anemometer and weather vane; see Fig. 4. Every six seconds the environmental conditions are measured and all values are saved in intervals of one our. The values that is saved is the average in that one our. The station is controlled by one computer placed in the same building.

Fig. 4. Meteorological station

3. Measures and TRNSYS model validation

To diagnoses the problem the cooling and heater demand for one standard year was calculated by means TRNSYS simulations. We introduced the climatologic data from average of 25 years registered by Meteorological National Institute, Meteorological Centre of Balearic Islands.

Figure 5 shows how the exchanger for heating which has a maximum available power of 298 kW is not enough to keep the offices at 25ºC. In these conditions the simulation shows that offices reached 41ºC and the Building 17 has an average peak of 130w/m^2.

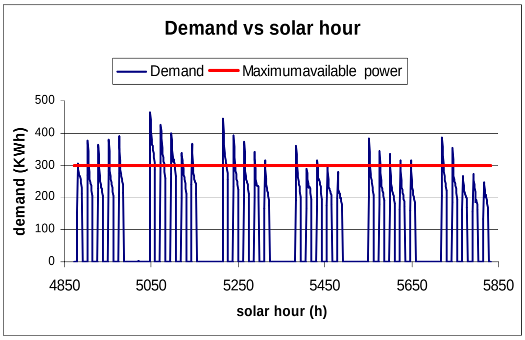

Fig. 5. Total power cooling demand computed during six weeks in summer

In order to solve those problems it has been proposed some solutions that have been evaluated with TRNSYS simulations. The first step was to validate this model with real measures. Fig. 6, 7 and 8 shows the results during some days in summer of 2004. A correlation coefficient shows that the TRNSYS model is very similar with the reality.

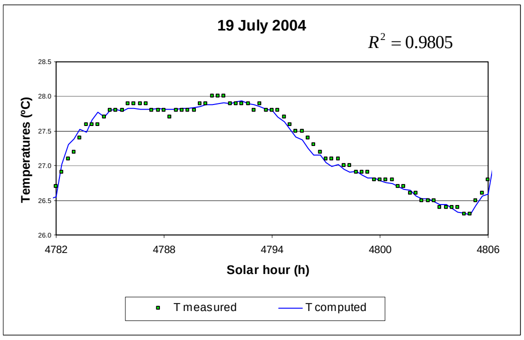

Fig. 6. Measured and computed temperatures in the prove office during 19 of July 2004.

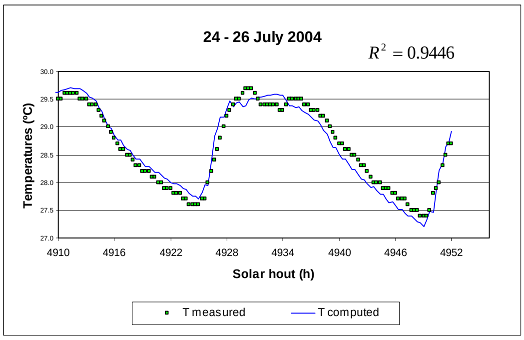

Fig. 7. Measured and computed temperatures in the prove office during 24 - 26 of July 2004.

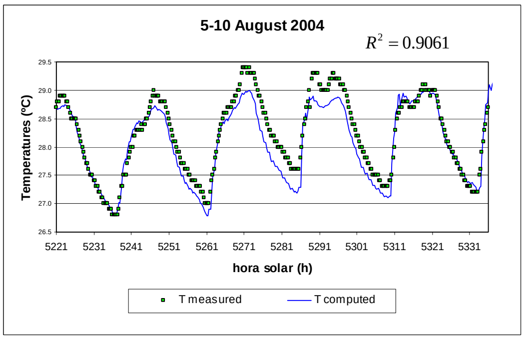

Fig. 8. Measured and computed temperatures in the prove office during 5 - 10 of August 2004.

4. Architectonical improvements actions.

The advantage to have a model capable to predict the thermal behaviour is that proposed solutions could be evaluated before actually executing them.

In the same way it is proposed nine architectonical improvements in order to solve the problem of NE façade by using ten simulations, the first one corresponds to an initial configuration of the building without the NE fixed curtain. Ten computed simulations correspond to the next ten architectonical improvements:

1) *Simulation 1:* Initial configuration of Building 17. $K_G = 1.70$.
2) *Simulation 2:* To add in all façade walls a polystyrene surface with a conductivity of 0.06 W/mK. With this improvement the building is according to the norms, $K_G=1.32$.
3) *Simulation 3:* To add an exterior fixed curtain in NE façade, it blocks a 70% of the total solar radiation. This is the actual configuration of the building, $K_G = 1.70$.
4) *Simulation 4:* To stick a reflectance surface in the armed glass of the NE façade inside the office to avoid the solar radiation. With

this improvement the building is not according to the norms, K_G=*1.70.*

5) *Simulation 5:* To put in the armed glass a plaster-cardboard with a thickness of 2 cm with a conductivity of 0.19 W/mK and a reflective layer. With this improvement the building is according to the norms, K_G=*1.42.*
6) *Simulation 6:* To add in the armed glass a plaster-cardboard with a thickness of 2 cm with a conductivity of 0.19 W/mK. In this improvement the building is according to the norms, K_G=*1.42.*
7) *Simulation 7:* To add in the armed glass a polystyrene surface with a thickness of 4 cm with a conductivity of 0.06 W/mK. With this improvement the building is according to the norms, K_G =*1.12.*
8) *Simulation 8:* To stick in the U-Glass inside of the air chamber a reflective surface to avoid increases the temperature inside it and to the reject the radiation. With this improvement the building is not according to the norms, K_G=*1.70.*
9) *Simulation 9.* To stick a reflectance surface in the U-Glass inside of the air chamber and to add a plaster-cardboard with a thickness of 2 cm with a conductivity of 0.19 W/ in the armed glass. With this improvement the building is according to the norms, K_G=*1.42.*
10) *Simulation 10:* To stick a reflectance surface in the U-Glass inside of the air chamber glass to reject solar radiation and to add in the armed glass a polystyrene surface with a thickness of 4 cm and a conductivity of 0.06 W/mK. With this improvement the building is according to the norms, K_G =*1.12.*

All simulations have been computed with the same environment conditions and the same comfort conditions, which consist in to keep all office at 25ºC in summer and at 20ºC at winter.

Figures 9 and 10 show the maximum consumed power from the ten architectonical improvements during summer and winter conditions respectively.

Comparing the improvements number one, four and eight in summer, the first one permits to have heaters gains in the offices by direct solar radiation and convection inside the NE air chamber, the case number four only permits to have heaters gains by convection and the eight case not permits neither solar radiation nor convection. From the computed results it is possible to separate the contribution by each one during summer conditions, so the fact is that the solar radiation represents a 32% of the total gains and the convection factor represents a 16%.

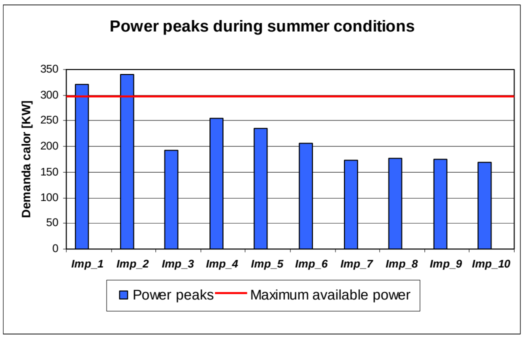

Fig. 9. Maximum available power in Building 17 and Power Peaks during winter conditions vs each architectonical improvement.

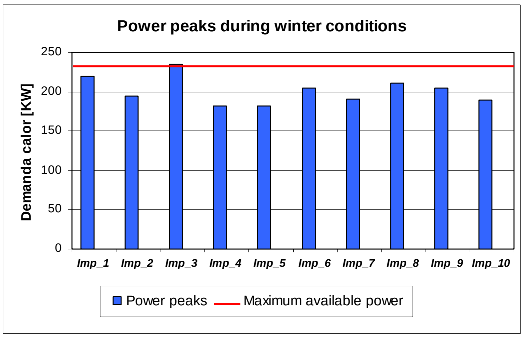

Fig. 10. Maximum available power in Building 17 and Power Peaks during winter conditions vs each architectonical improvement.

Another important conclusion is that in spite of the fact that the improvement number two is according to the norms it can bee see that this improvement is the worst for summer conditions. This is evidence that the norms need to include transitory studies like TRNSYS to avoid the design problems in the buildings.

From the others improvements it can bee see that it is not necessary to add another more expensive materials like insulation materials or plaster-cardboard to solve the problem comfort.

In the other hand, configuration number three belongs to the urgent solution carried out during summer 2003 and it is one of the bests for summer conditions, but it is the worst during the winter. So another new solution consists a mixed improvement between the case number one and the case number three, that it's consists in a mobile exterior curtain which in summer is installed and in winter not. Figure 11 shows the energy saving to respect the initial configuration of the Building 17 during all year for all cases.

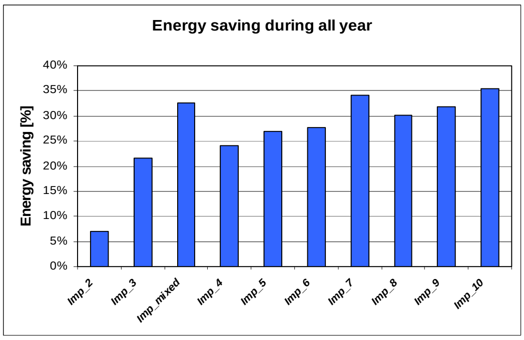

Fig. 11. Energy saving during all year versus architectonical improvements.

The actual configuration is the worst solution during all year and the mixed improvement between number one and number three is one of the bests; this mixed solution can reach an annual energy saving of 33%, so it's an annual saving of 27 MWh and the power peak per surface is 70 w/m^2 during summer and 85 w/m^2 during the winter.

Finally annual economic and CO_2 emissions saving are calculated from the previous calculus. Supposing a price of 0.05€/KWh of heating and a 0.07 €/kwh of cooling (those prices are approximately the prices of the ParcBit) it is calculated the annual economic saving, it is showed in Fig. 12. The mixed improvement supposes an annual economic saving of 35%.

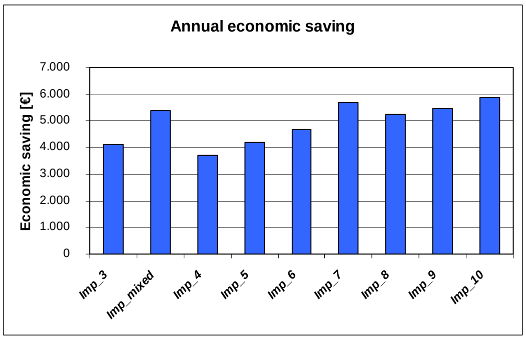

Fig. 12. Annual economic saving for all architectonical improvements

Now, it's calculated the contamination saving supposing 0,26 Kg of CO_2 per kWh produced, see Fig. 13. It is considered a 0.6 of efficiency from production in the energy plant to consume in the building.

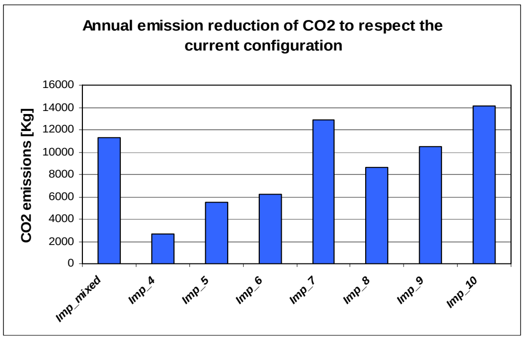

Fig. 13. Emission reduction of CO_2

5. Improvement actions to management energy.

In order to improve the offices' comfort and at the same time contribute to energy saving there are some ways that consist in a properly control of the installations of the building. Three kinds of management actions are proposed, the first one consists in to avoid an excessive cooling of the building during winter conditions, the second one consists in to increase in 1ºC the comfort temperature during summer and the last one consists in free-cooling by ventilation when ambient temperature is similar to the comfort temperature [5,6].

5.1 To avoid an excessive cooling of the building during winter conditions.

In this case is evaluated if it is convenient or not to avoid an excessive cooling of the building during the winter conditions. Now, the model consists in to avoid the offices temperatures not to bring down of a determinate temperature. Three different top temperatures are evaluated: 17ºC, 15ºC and 12ºC. The computed calculus show that those modes increase the heating energy demand but reduce the power peaks, see Fig. 14 and 15.

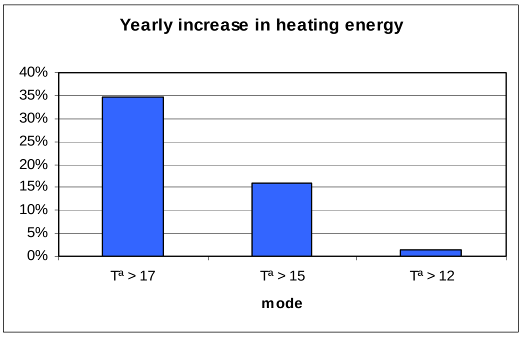

Fig. 14. Annual increase in heating energy for the three proposed modes: 17ºC, 15ºC and 12ºC.

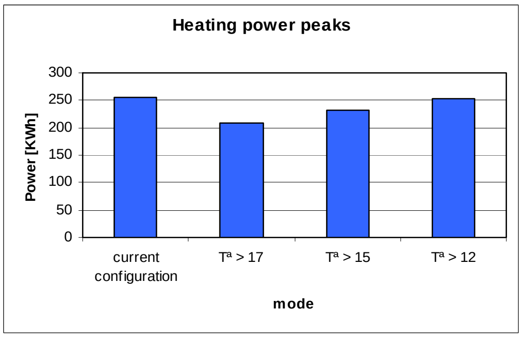

Fig. 15. Heating power peaks for modes: current configuration, 17ºC, 15ºC and 12ºC.

This solution could be interested if the installed power of the building wasn't enough to acclimatize it.

5.2 To increase in 1ºC the comfort temperature during summer conditions.

This section evaluates the energy saving produced during summer increasing the comfort temperature from 25ºC to 26ºC. During summer is when more energy is demanded and it can be interesting to rise the comfort temperature when is required by the environmental conditions. Figure 16 shows the energy saving in the actual configuration of the building (case three).

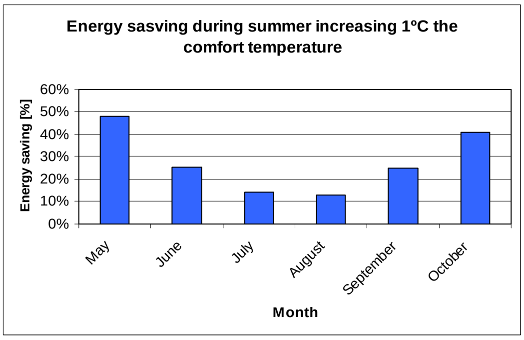

Fig. 16. Energy savings at summer increasing the comfort temperature from 25ºC to 26ºC.

With this improvement it can be a saving of a 20% from the annual cooling energy.

5.3 Free-cooling by ventilation

At some periods, especially during spring and autumn the environmental conditions are enough for heating or cooling the buildings only with an increasing of the ventilation, hence the internal heating gains are dissipated at the exterior. This system has the advantage that is needed less energy to ventilate than to acclimatize whit conventional systems, so the saving increases as much us renovations per hour made. To evaluate in this case the energy saving it's simulated ventilation which introduces exterior air to the offices when the ambient temperature belongs to the interval of comfort temperatures. Figure 17 shows the energy saving by the three cases computed: 5, 10 and 20 renovations per hour.

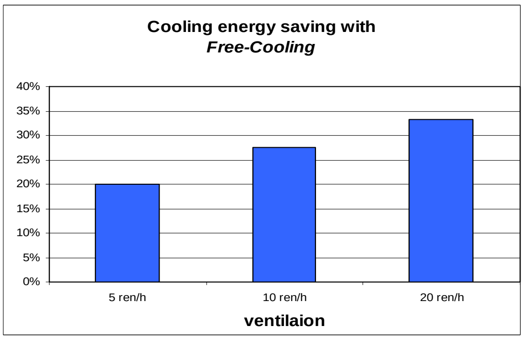

Fig. 17. Cooling energy saving with free-cooling for 5, 10 and 20 ren/h.

The calculations show that it's possible to reduce 33% of energy with free-cooling during summer.

5. Conclusions

Models in TRNSYS are a good system to simulate the reality and they can represent the different scenarios to evaluate energy and economic savings in short period of time and without spend the money.

The simulating programs should be used in the design of a building by the architects and engineering for avoid habitability problems, high energy consumption and CO_2 emissions. Using the energy building software simulators by the designers allow to take the properly decisions and create sustainable buildings, especially when are made with new materials.

The cheapest solutions, like the fixed curtain, are useful for solve quickly the comfort problems in summer conditions but for the winter they make spend more energy in lighting and calefaction. The best solutions are the ones who are tough for the all year with all the conditions, analyzing the life cycle and the savings in a medium-long period of time. The power peak per surface is reduced from 130w/m^2 to 70w/m^2 during summer conditions.

Another important conclusion is that in spite of the fact that the improvement number two is according to the norms we see that this improvement is the worst for summer conditions. This is evidence that the norms need to include transitory studies like TRNSYS to avoid some problems in the buildings design in the future.

On consequence to avoid an excessive cooling of the building is to increase the heating energy demand but in the other hand another consequence is to prevent higher power peaks.

The calculations show that it's possible to reduce 33% of cooling energy with free-cooling and a 20% with increasing 1ºC the comfort temperature during summer.

From that study it has been possible to improve the energy norms of the ParcBit (NEPbit).

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