SIMULATION OF A PHOTOVOLTAIC HYBRID FACADE

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ABSTRACT

The conception of complex buildings with innovative facade elements often demands dynamic building simulations. In some cases the required thermal parameters of the components must be obtained by experimental investigations. This paper describes this procedure exemplary for a photovoltaic facade, which allows the combined utilization of electrical and thermal energy.

The parameters for a TRNSYS simulation could be obtained with the help of a PASSYS testcell. The results show that the total energy transmittance (g-value) of such a facade strongly depends on the ambient air temperature.

INTRODUCTION

Double skin facades, consisting of a massive wall with a transparent or semitransparent curtain layer, are used increasingly, since they have a number of advantages. This technology can be used in new buildings as well as in the retrofitting of old buildings.

By an intelligent control of ventilation flaps and use of additional fans the thermal behaviour of the facade can be adapted to the conditions of use and to the actual weather conditions. An overheating of the building during the summer can be prevented by opening a channel between the air gap and the ambient air. If in contrast the air from the gap is passed into the building solar gains can be used for heating purposes. Thus the control of the air flow causes a valve-effect, i.e. high solar gains can be combined with low heating losses.

For an optimized design of the facade and of the HVAC-system of the building a quantitative knowledge about the thermal behaviour of the facade is necessary.

In general, passive-solar components can be described by the U-value (heat loss coefficient) and the g-value (total heat or solar transmittance). The definition of the U-value can be applied to double skin facades without difficulties, whereas the definition and determination of the g-value causes some problems.

In the case of a simple glazing the g-value is defined as the part of the radiation which is passed through the glazing. It can be derived only from the optical properties of the glasses. But in the case of an opaque facade the more general definition must be used: The g-value is this fraction of the incident radiation energy which can be used for the heating of the building. It is shown in this paper that the g-value of a double skin facade can strongly depend on the ambient air temperature and thus cannot be used in the usual way.

The procedure to obtain the thermal parameters is shown exemplary for a photovoltaic (PV) hybrid facade. Such a facade allows besides the generation of electrical energy additionally the utilization of the thermal energy caused by the absorption of the solar radiation.

To calculate the possible saving of heat energy by use of such a facade a TRNSYS simulation was performed. Since in this case only the thermal properties of the PV facade were of interest it was tried to use the TRNSYS type 37 („Attached sunspace“) for the model. Because of the differences between an attached sunspace and a PV facade at first some of the required parameters had to be determined by a preliminary outdoor experiment and following calculations.

THE PHOTOVOLTAIC FACADE

For the experimental investigations a photovoltaic facade was constructed, consisting of the PV-modules, an air gap and a massive brick wall. It is shown in fig. 1.

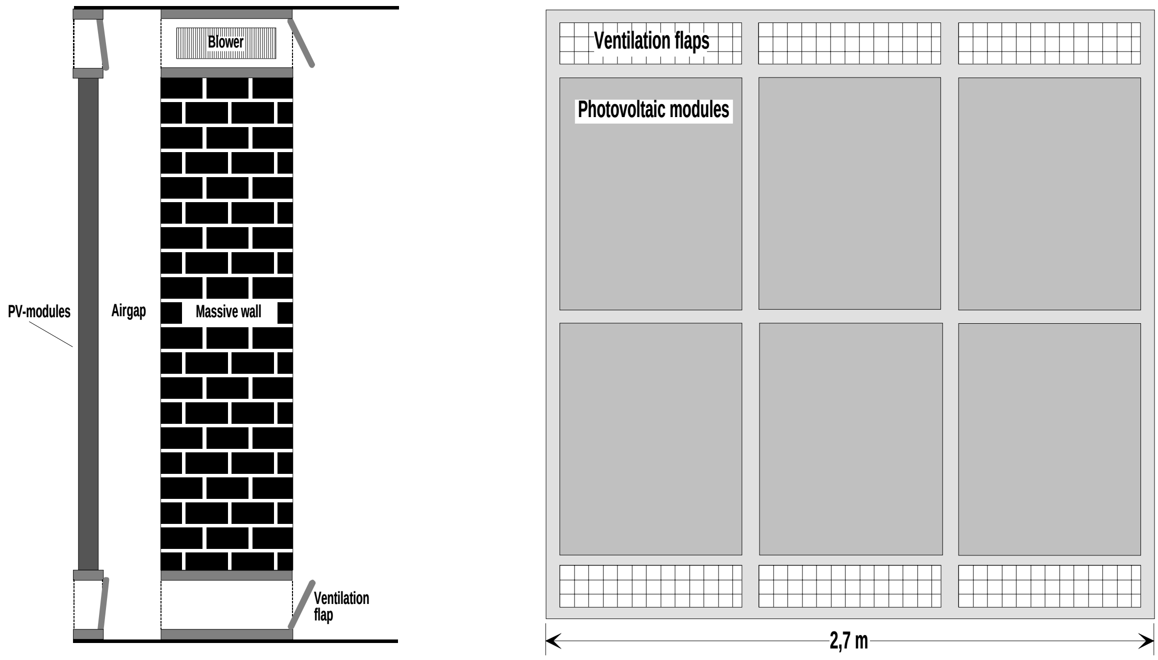

Fig. 1: The photovoltaic facade

The PV-area consists of 6 prefabricated modules with a total effective area of 4.9 m^2. The PV cells (monocrystalline silicon, type MIS-I) are embedded in glass panes (total thickness of the modules 8.5 mm). During all of the experiments the modules were MPP-tracked and grid-connected.

The ventilation flaps above and below the PV modules allow an air exchange between the air gap and the ambient air during the summer time to prevent an overheating of the modules. During the described experiments these flaps stayed closed.

The flaps above and below the massive wall are intended for the air exchange between the air gap and the room. This air exchange is driven by three additional tube axial fans behind the upper flaps. The electrical power consumption of each fan was 18 watt.

The massive wall had a thickness of 24 cm and was made of bricks with a density of 1.8 $g \cdot cm^{-3}$ and a thermal conductivity of 0.9 W/(m·K).

In a real application of course an additional insulation layer must be added to the wall. However, during the experiments the wall was used without insulation in order to achieve a better identifiability of the thermal parameters of the wall.

THE PASSYS TEST PROCEDURE

The experiments were done using a so-called PASSYS test cell [1]. These test cells were developed during an European research project about passive solar systems. They are appropriate to determine the heat loss coefficient U and the solar transmittance g of passive solar components under natural climate conditions.

Every test cell consists of a well insulated test room and a small service room at the northern side. The temperature of the test room can be controlled by a heating and cooling device. The test component is mounted in an insulated frame at the south oriented side of the test cell. The aperture of the frame (2.7 m x 2.7 m) enables the installation of facade elements in original dimensions.

The other walls of the test cell are well insulated (40 cm) to minimize the heat exchange with the surroundings.

A cross section of a test cell is shown in fig. 2.

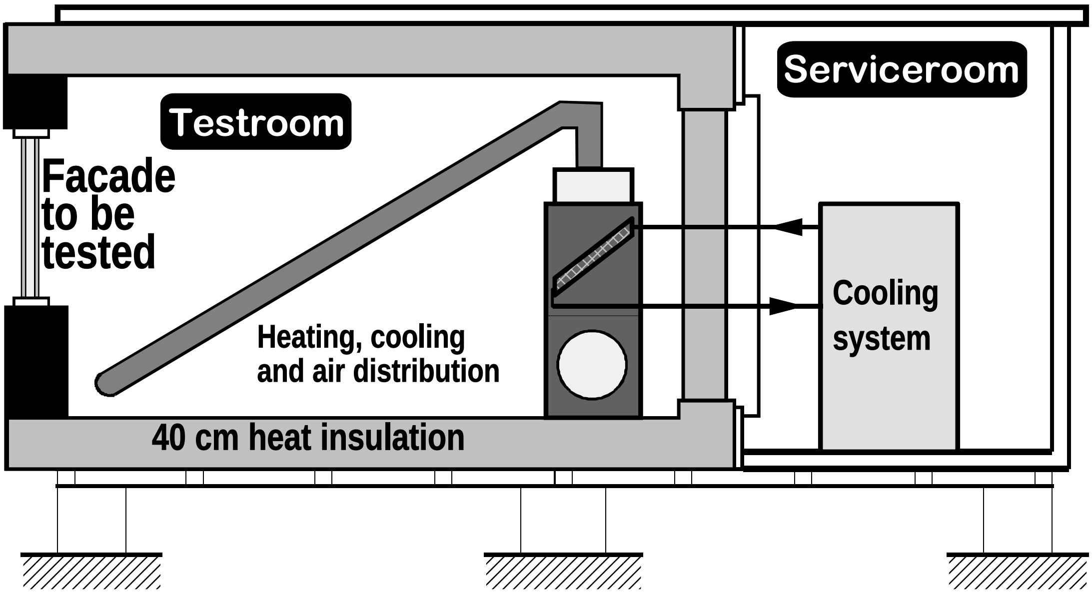

Fig. 2: Cross section of a PASSYS test cell

For the analysis of the PASSYS experiments both the test cell and the test component are modelled by thermal RC networks. Fig. 3 shows the network used to describe the thermal behaviour of the PV facade. More details of the PASSYS experiments with the PV facade are given in [2] and [3].

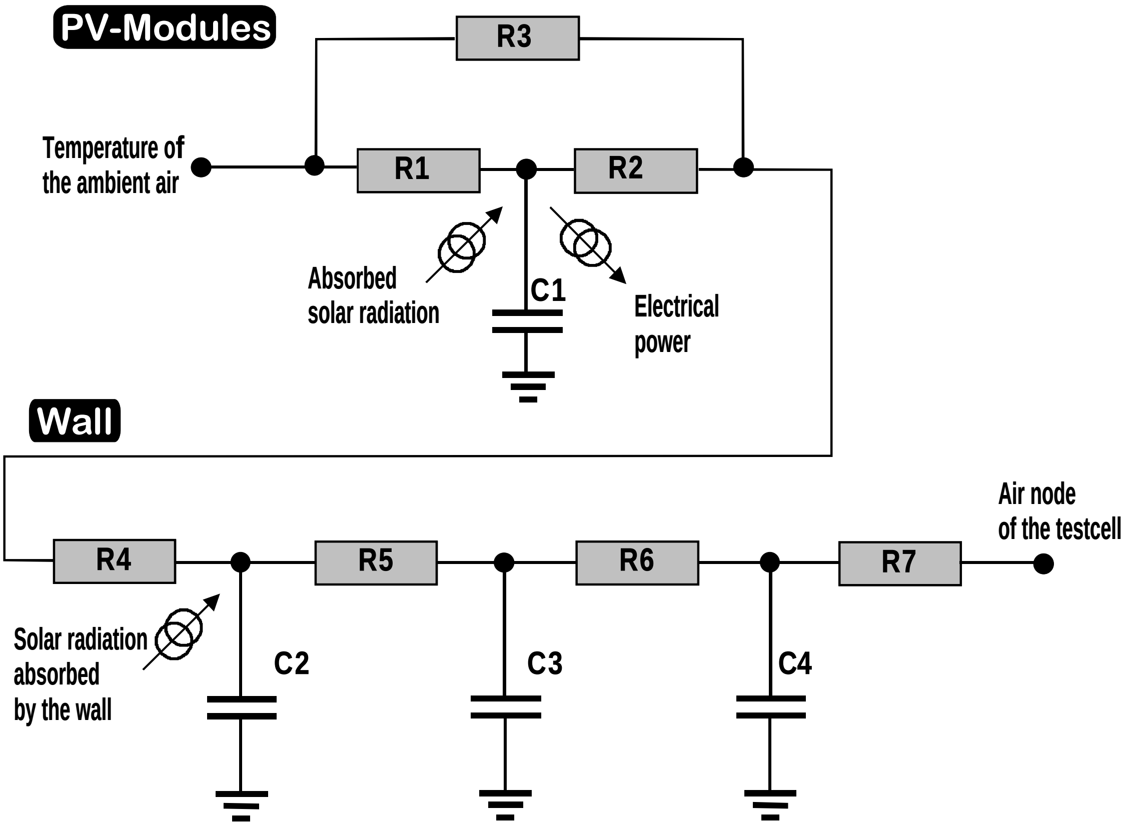

Fig. 3: RC network as thermal model for the PV facade

The values of the individual resistances and capacitances are obtained by parameter identification. This is done using the Monte-Carlo-procedure described in [4].

For the thermal modelling of the facade within TRNSYS it is necessary to determine the parameters of the TRNSYS type 37. Only some of these parameters are known (geometry, thermo-physical properties of materials). To get the other parameters (e.g. which describe the influence of convection and radiation) the following procedure was applied:

The temperature development in the air gap was calculated using the type 37 and a first guess of parameters. This temperature curve was compared to the measured one. Now the TRNSYS parameters were varied as long as the best possible conformity between measured and simulated air temperature was reached. Fig. 4 shows a part of the two curves. The total duration of this calibration was six weeks. The ambient air temperature during this period was in the range between -3 °C and 25 °C.

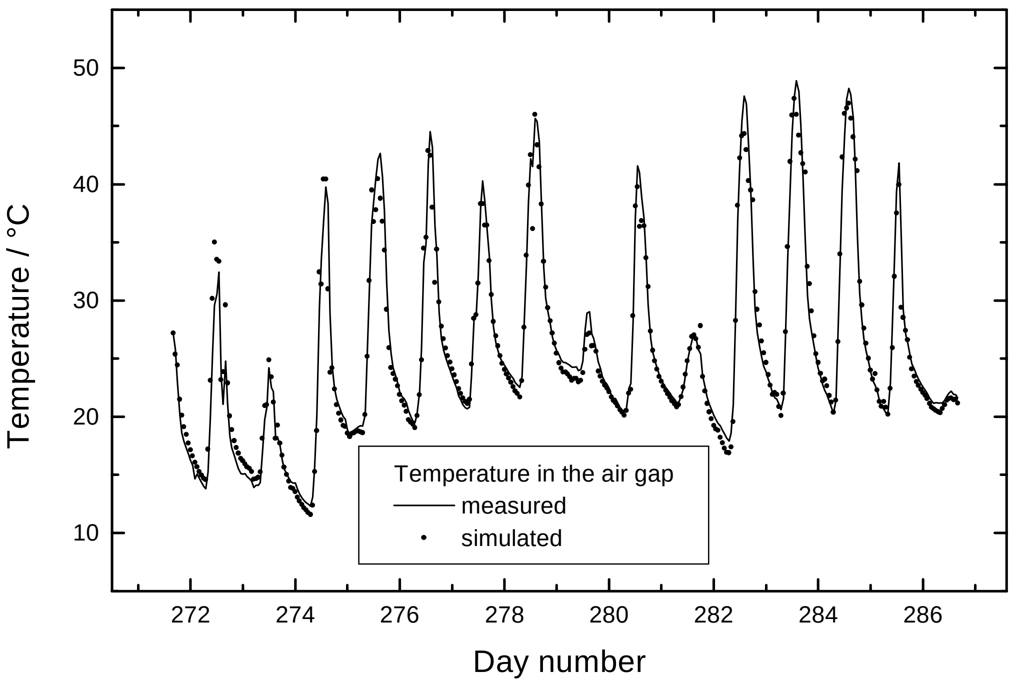

Fig. 4: Measured and simulated temperature in the air gap

The parameters obtained this way have not necessarily a specific physical meaning. The physical TRNSYS model was transformed into a mathematical lumped parameter model which describes the relation between input and output values with a sufficient accuracy.

THE TRNSYS SIMULATION

With the use of the determined parameters now a whole-year simulation of a model room with adjoining PV facade could be performed. The model room had dimensions of 5 m x 2.7 m x 2.7 m. For the east wall, the west wall, the ceiling and the floor adiabatic conditions were assumed. The north wall and the south wall consist of 20 cm concrete with 10 cm heat insulation. The south wall is equipped with the described PV facade. The ventilation flaps between the air gap and the room were opened if the temperature in the gap was greater than that in the model room. At the same time the additional fans were switched on. The temperature in the room was fixed to 20 °C.

The annual heat energy demand for the model room was calculated using the german test reference year TRY02 (northern and western lowlands of Germany).

It turned out that the amount of heat energy gained from the PV facade strongly depends on the used mass flow rate produced by the fans. Fig. 5 shows the calculated heat energy demand in dependence on the mass flow rate. The additional heat production by the motors of the fans was not taken into account.

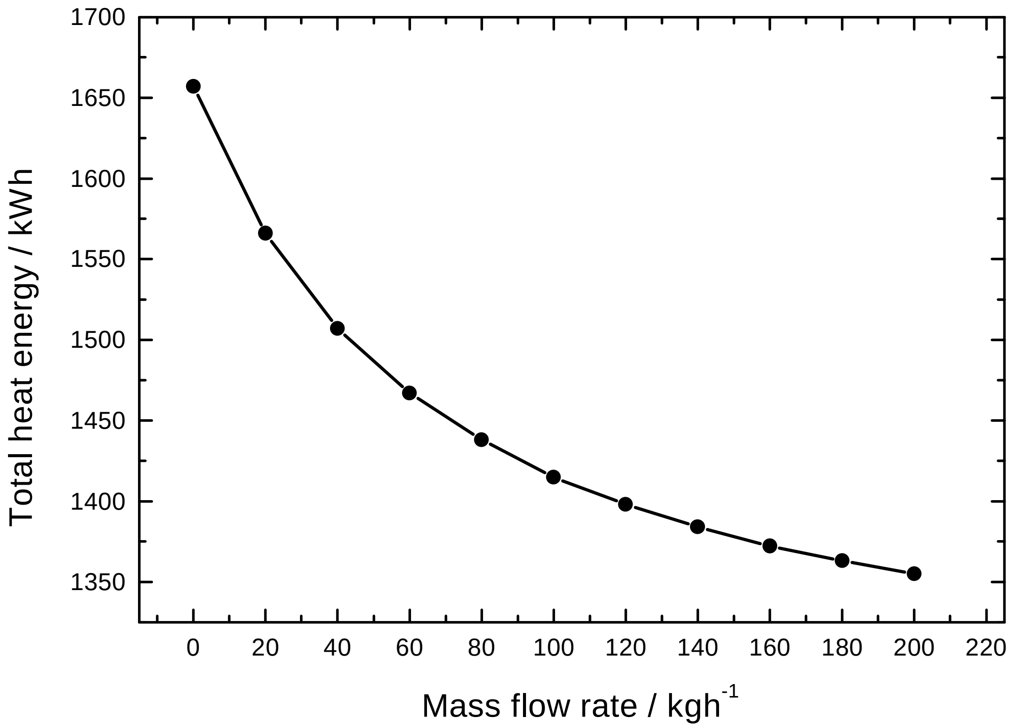

Fig. 5: Annual heat energy demand in dependence on the mass flow rate

In practical applications it is important to compare the amount of electrical energy needed for the fans with the amount of saved heat energy.

THE G-VALUE

In the case of a simple glazing, the whole amount of energy, which passes through the glasses, contributes to the solar gains. Since this fraction only depends on the properties of the glasses, which are nearly independent of the current temperatures, the g-value can be treated as a constant value.

The definition and determination of the g-value in case of the described PV facade is more complicated. Not the whole amount of energy, which is absorbed in the air gap, contributes to the heating of the room. A part of this energy get lost by radiation and heat conduction through the PV modules. The amount of this losses depends from the ambient air temperature. Therefore, in this case the g-value is expected to depend on the ambient air temperature too. The simulations confirmed that the g-value decreases with falling temperature. The following two figures show the calculated g-value in dependence on the mass flow rate and on the ambient air temperature respectively.

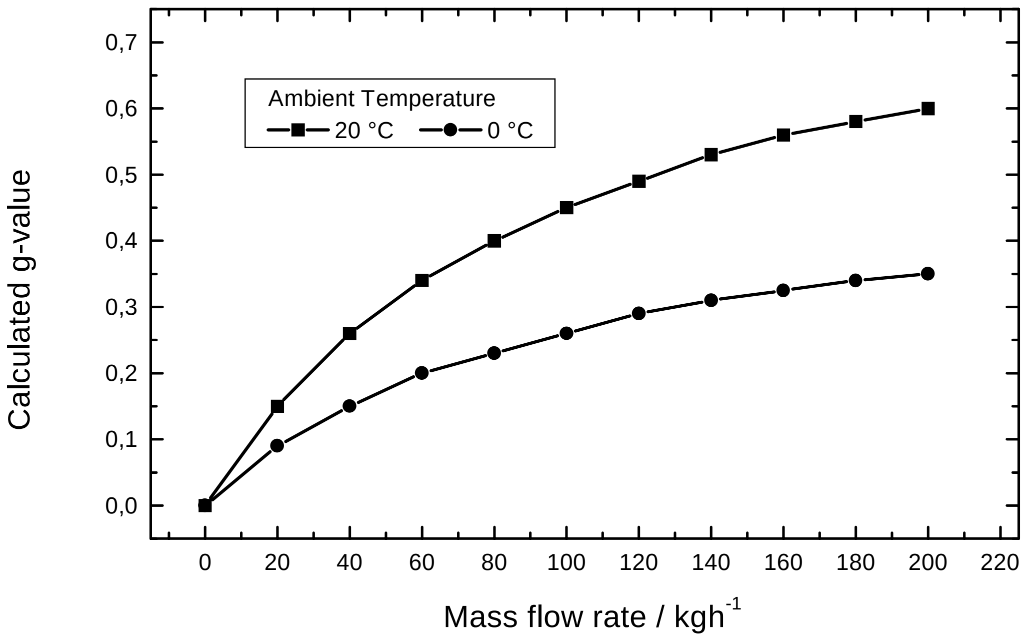

Fig. 6: Solar transmittance in dependence on the mass flow rate

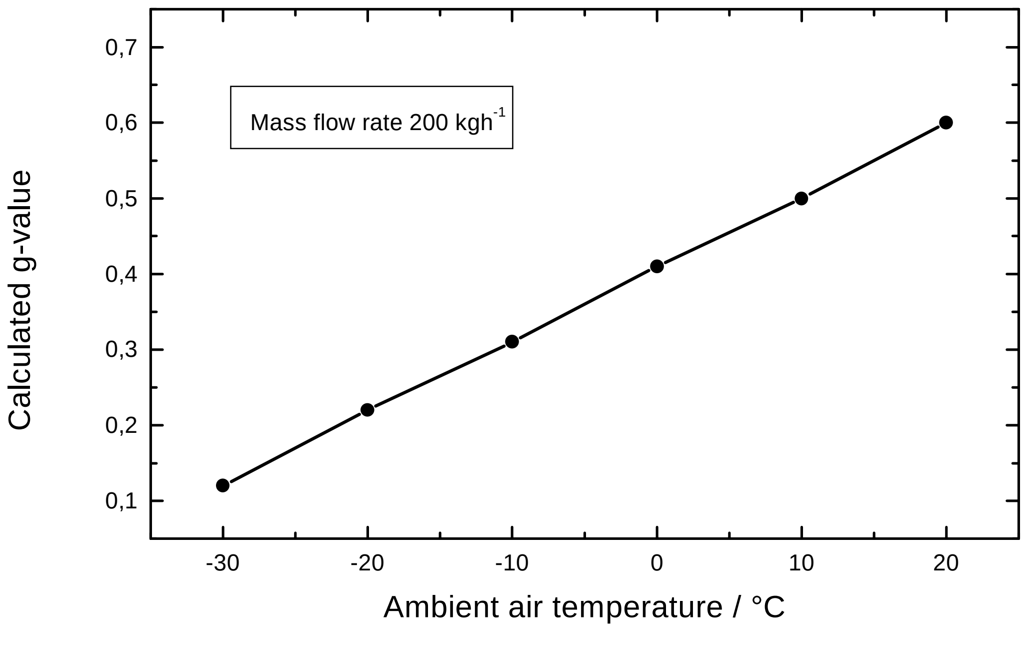

Fig. 7: Solar transmittance in dependence on the ambient air temperature

Especially the last figure clearly illustrates that double skin facades require an extension of the concepts for the assessment of simple passive solar components. The strong dependence of the g-value on the ambient air temperature makes it impossible to carry out a simple estimation of the saving of heat energy by such a facade. Consequently, detailed building simulations are necessary.

An increase in the g-value at low ambient air temperatures can be achieved only by an improved heat insulation between the absorbing layer and the ambient air. In case of the described PV facade this is possible only by an additional glass layer on the external side. This would probably effect higher costs and a lowering of the electrical efficiency.

The high g-value at high air temperatures must not necessarily lead to an overheating during summer, since the energy gain can be nearly switched off by closing the ventilation flaps.

SUMMARY

It was shown that even a relative simple double skin facade can not fully be described by the models developed for passive solar components. This example shows once more the necessity of detailed building simulations.

The described procedure of adapting an existing TRNSYS model to a new component is applicable also to other problems. For the determination of the required parameters and for the validation of the models the PASSYS test cells are appropriate tools.

ACKNOWLEDGEMENTS

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