

AUTOMATIC SUN SHADES, AN EXPERIMENTAL STUDY

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ABSTRACT

Can automatically controlled sun shades significantly reduce summer heat gain and optimize winter passive solar heating in residential applications?

This paper reports the results of a two year study using a pair of full height test cells, one of which had a microprocessor controlled movable external or internal sun shade, while the other was an unshaded reference case. For comparison purposes the experimental cell was also operated with a whole house fan. The performance of selected representative tests are reported here for both summer and winter conditions.

This paper also describes how hourly data recorded in these test cells was used to validate HEED, a well known whole-building energy simulation program. Once HEED was shown to accurately predict the measured performance of the shades in the test cells, then it was used to model the performance of these same automatic operable shades in each of California's sixteen climate zones.

1. INTRODUCTION:

This project demonstrates the feasibility of a new kind of microprocessor controller that can intelligently operate automatic window shades in order to minimize cooling energy costs. Experiments showed these automatically controlled shades always reduced the peak indoor temperatures and the number of overheated hours in the experimental cell as compared to the control cell.

Fortunately, during the periods when daytime temperatures are too hot, in most California climate zones the night-time

temperatures fall into the comfort range. The controller's task is to close the shades in order to slow down heat gain into the interior thus to preserve evening "coolth" in the building's internal mass so that it can 'coast' comfortably through the next day's heat.

The controller built for this project is similar to a conventional programmable thermostat, but with the addition of an outdoor temperature sensor and a modified microprocessor to hold the expanded control logic. There is no thermostat on the market today that reads both indoor and outdoor temperature and that uses a microprocessor to control a whole-house fan and operable shades, in addition to an air conditioner and furnace. Clearly this new product would have the greatest appeal to homeowners in those climates where this strategy can completely eliminate the need to install an air conditioner.

Commercially available electrically operated venetian blinds were used in this study. Already on the market, especially in Europe, are awnings that extend and retract, vertical external operable louvers, internal operable draperies and venetian blinds. However, none of them has a residential-scale controller, similar to the microprocessor-thermostat developed here, that could read indoor and outdoor temperatures and operate shading devices to optimize indoor temperatures.

2. THE OPPORTUNITY:

In California, homes tend to be designed with an abundance of windows. As a consequence, during the hottest periods, the solar radiation gain create uncomfortably warm indoor conditions, thus causing air conditioners to come on. If this radiation can be blocked in some automatic way, indoor conditions will be moderated.

Unfortunately, most homes are not designed to effectively 'harvest' this resource. Proof of this is the common situation on a sunny day where a home's air conditioner is running when outdoor air temperature is quite pleasant. Or in spite of cool temperatures the night before, the house is now overheating. The problem clearly has something to do with the way that particular home is designed and operated.

Air conditioning represents the second largest category of electricity consumption in California homes. If residential air conditioning in California uses roughly .3QBtu (Quads), and if this new product leads to the elimination of just one air conditioner in a thousand, then it could save over 100,000 Mwhr per year. It is also worth noting that this product will have a significant impact during the hours of the day when California's Electric Utilities are experiencing their maximum peak loads, in mid-afternoon on the hottest days of the year, thus it will help 'shave the peaks'. Because the fan it controls also runs at night to 'night flush' the home, when the utilities have their lowest load factor, it will help to 'spread the load', increasing system utilization efficiency. Thus this new product, targeted for this potentially huge residential market, will benefit both ratepayers and utilities alike.

3. PREVIOUS PROJECT:

Previously we presented the construction of the test cells and also described a new kind of residential thermostat that reads both indoor and outdoor temperatures, and contains a microprocessor programmed to optimally control a whole-house fan (ASES 2002, 2003). This fan lets the home take advantage of the greatest source of free cooling energy in most California climates, night outdoor air. Toward the end of that earlier experimental series, almost as an afterthought, we ran two tests that yielded unexpected results. In the first we blocked solar radiation from the window in our test cell, and in the second we blocked both radiation and conduction through that window. These two tests had a greater impact on indoor air temperature than any of the other ventilation and night-flushing strategies we had tested. This raised the prospect of using this same microprocessor to automatically control window shading devices.

4. DESIGN OF THE EXPERIMENTAL SYSTEM

The objective for this project was to install on these full-height test cells two different types of operable sun controls, one external and one internal. Each experiment ran automatically under computer control until it captured a string of 4 to 6 days of weather hot enough to activate the system. Data from both the experimental cell and the unshaded control cell is automatically recorded every few

minutes. These data can be directly read into spreadsheets and the results plotted as the experiments are in progress.

The controller consists of a data logger microprocessor with thermistors to measure air temperature. A computer connected to the microprocessor contains the control programs and collects and stores experimental data. In the commercial version the control program finally chosen will be loaded onto the e-prom in the thermostat. The two test cells each have a 2'x2' double pane window, one unshaded and the other with an automatic venetian blind that could be installed on the interior or the exterior. The experimental cell also has a controlled ventilation system, providing 0.7 air changes of infiltration, or up to 3.9 air changes when testing economizer cooling. Both cells have 24.8 sq.ft. of brick as a floor slab.

Summer Rule: In the summer, two conditions must be satisfied to close the shade. The first condition is that shading is provided whenever indoor temperature is above 70 °F, which is assumed as the shade line. The second condition is that a black south-facing metal plate (on the same elevation as the window) must be warmer than the air temperature which indicates that the sun is facing that window and it is receiving solar radiation.

Winter Rule: The shade system is used to avoid overheating of the building through the windows. The shade system is set so that the louvers will close if the indoor temperature is higher than a specified value, in this case 75 °F (23.9 °C), or 3 °F lower than the value of comfort high (78 °F).

5. EXPERIMENTAL PERFORMANCE OF SELECTED SHADING SYSTEMS

Dozens of different experiments were performed to optimize the performance of the different systems. The first three series in the experimental cell use the summer rules and the second two series use the winter rules (Table 1).

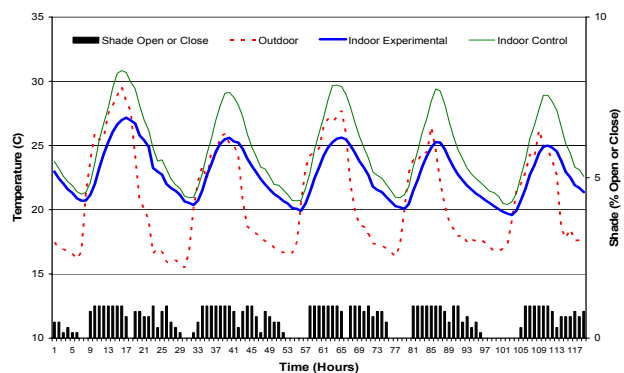


Fig. 1: Series 1, External Shades

Series 1, External Shades (Summer mode): In this series performed between August 29 and September 2 of 2003, the venetian blinds are on the outside face of the window (exterior of the test cell) and the ventilation system is turned off, allowing only basic infiltration, for a minimal air change rate

Series 2, Internal Shades (Summer mode): This series, between August 9 and 12 of 2003, is the same as the previous series except that the automatic blinds are now on the inside face of the window (interior of the test cell).

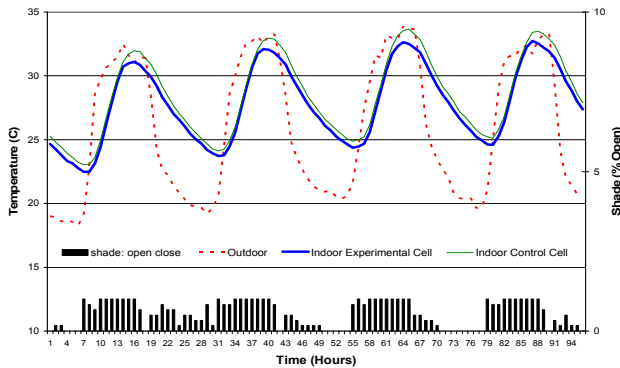


Fig. 2: Series 2, Internal Shades (Summer Mode)

Series 3, Ventilation System (Summer mode). In this summer series performed between September 23 and 26 of 2001, the window is unshaded, and the ventilation system is turned on, with an air change rate that varies between 0.7 and 3.9 air changes/hour. Comfort low is 65 °F and comfort high is 78 °F (18.3 to 25.5°C).

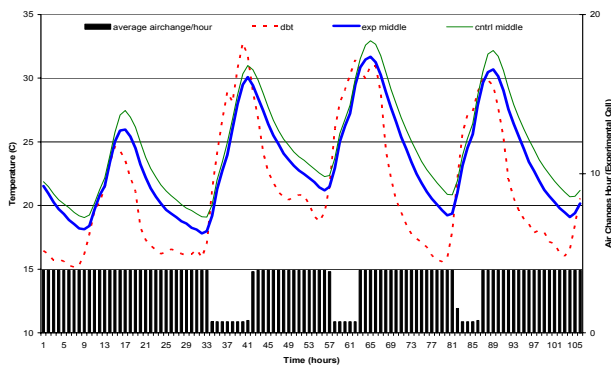


Fig. 3: Series 3, Ventilation System (Summer)

Series 4, External Shades (Winter Mode): In this winter series performed between December 3 and 10 of 2003, the automatic blinds are on the exterior of the building, and the ventilation system is turned off. The rules for the venetian

shades are set for the winter mode. Notice that only rarely do the shades close to prevent overheating (Fig. 4) and they do this effectively.

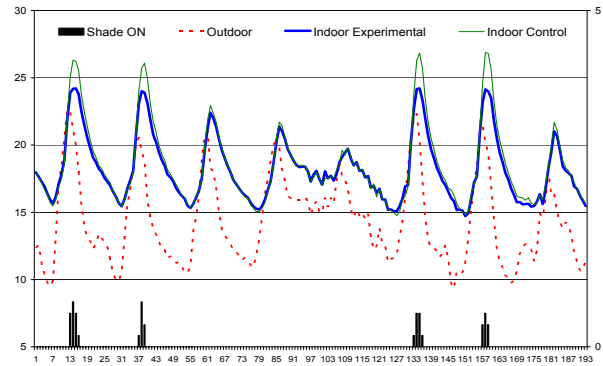


Fig. 4: Series 4, External Shades (Winter Mode)

Series 5, Internal Shades (Winter mode): In this series performed between November 18 and 25 of 2003, the shades are now on the interior of the building. The ventilation system is turned off and the rules for the shades are also set for the winter mode. Again notice that the shades close only rarely to prevent overheating.

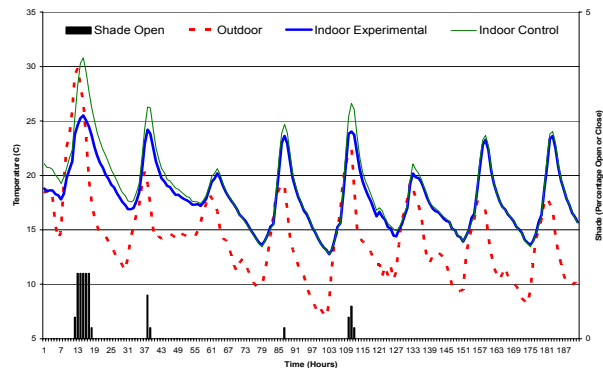


Fig. 5: Series 5, Interior Shades (Winter mode)

6. DISCUSSION OF EXPERIMENTAL RESULTS

The comparison of the average maximum temperatures is used to evaluate the performance of each series.

6.1 Comparison of Average Maximum Temperatures in the Summer

Comparison of the average maximum temperatures between the control cell and experimental cell is indicative of the performance of the system (Table 1). The larger the difference, or temperature drop, between the maximum averages in these two cells, the better the performance of the experimental cell. The temperatures in the experimental and

control cells had previously been compared in a series of identical calibration tests and a correction factor is used to adjust a for a 0.5 °C (0.9°F) difference between the cells.

Unshaded windows with the automatic ventilation system have a slightly better cooling effect than the automatic interior shaded windows. However, the with the shading system on the outside performance improves greatly with an Average Temperature Drop = 3.9 °C (7.0°F).

TABLE 1: AVERAGE MAXIMUM TEMPERATURES (°C)

	Series	Outdoor Temps	Experi-mental. Cell	Control Cell	Temp. Drop (°C)
1	External Shades Vent Off	27.2°C (81.1°F)	25.7°C (78.3°F)	29.6°C (85.3°F)	3.9°C (7.0°F)
2	Internal Shades Vent Off	32.9°C (91.2°F)	31.8°C (89.2°F)	32.6°C (90.7°F)	0.8°C (1.4°F)
3	Vent On Unshaded Window	29.7°C (85.5°F)	29.6°C (85.3°F)	30.9°C (87.6°F)	1.3°C (2.3°F)
4	External Shades Vent Off	20.6°C (69.1°F)	22.4°C (72.3°F)	24.0°C (75.2°F)	1.6°C (2.9°F)
5	Internal Shades Vent Off	20.6°C (69.1°F)	22.9°C (73.2°F)	24.7°C (78.3°F)	1.8°C (3.2°F)

6.2 Comparison of Average Maximum Temperatures in the Winter

In winter the shades are used to reduce overheating. The performance of the system in the winter season can be determined by comparing the differences in the average maximum temperatures between the control cell and the experimental cell when the shade is outside or inside the window of the experimental cell (Series 4 and 5, Table 1). In both cases the shade closes only occasionally but keeps the cells from overheating on warm days (Figs 4 and 5).

7. RESULTS: VALIDATION OF HEED USING EXPERIMENTAL DATA

HEED, Home Energy Efficient Design, is a user friendly design tool intended to help homeowners, architects, and builders design more energy efficient homes. It is available at no cost via the internet (www.aud.ucla.edu/heed). It has been validated using the ASHRAE BestTest procedure (the results are reported on this same web site). HEED was used to predict the impact of these automatic sun-shades in climates throughout California.

The first step was to validate HEED. This was done by comparing the indoor air temperature measured in the test cell to the corresponding temperature calculated by HEED. Inside HEED is a calculation kernel also known as SOLAR-5, which requires a physical description of the building (the test cells), plus climate data including the outdoor air temperature, beam and total horizontal solar radiation. HEED can simulate the logic of the microprocessor thermostat used to operate the automatic internal and external louvers, as well as a whole house fan. The performance of the external and internal shades is calculated using ASHRAE and ACM algorithms¹. A control cell, with no shading or fan, was also simulated

TABLE 2: HEED VALIDATION TESTS

HEED Validation Tests	Temperature Difference between Data Recorded in the Experimental Cell vs. Temperatures Calculated by HEED			
	Experimental Test Series	Peak Hottest Hour	Peak Coldest Hour	Average all Hours
1. External Shades Experimental Cell Summer		-0.12°C (-0.21°F)	0.66°C (1.18°F)	0.24 °C (.44°F)
2. Internal Shades Experimental Cell Summer		-0.62°C (-1.11°F)	0.22°C (.40°F)	-0.14°C - (.26°F)
3. Whole House Fan Experimental Cell Summer		1.30°C (2.34°F)	-0.57°C (1.03°F)	0.58°C (1.04°F)
4. External Shades Experimental Cell Winter		-1.50°C (-2.70°F)	-2.94°C (-5.31°F)	-1.94°C (-3.50°F)
5. Internal Shades Experimental Cell Winter		0.72°C (1.31°F)	-3.51°C (-6.51°F)	-2.37°C (-4.27°F)
C. Control Cell Summer No Shades No Fan		-0.72°C (-1.31°F)	-0.82°C (-1.47 °F)	-0.30°C (-.54°F)
Mean Temperature Difference		-0.15°C (-0.28°F)	-1.16°C (-2.08°F)	-0.65°C (-1.18°F)
Standard Deviation		0.93 (1.68)	1.54 (2.78)	1.1 (1.98)

The results of these validation studies (Table. 2) shows how well HEED predicts the actual recorded indoor temperatures. The results show that in most cases HEED tends to predict indoor air temperatures that are slightly below those recorded in the test cells, however the differences are extremely small. On average HEED is extremely accurate at predicting the average indoor temperature to within -0.65°C (-1.18 °F) over all hours of all tests for both summer and winter climate conditions. HEED is even more accurate at predicting the indoor maximum hottest hour to within -0.15 °C (-.28 °F). HEED is slightly

less accurate at calculating the indoor minimum coldest temperatures to within 1.16 °C (-2.08 °F). Notice that this is primarily due to the fact that under winter conditions HEED is least successful in simulating indoor minimum temperatures, predicting that they will be up to 3.51 °C (6.5 °F) colder than were actually recorded.

In Summary, HEED is shown to be quite accurate at predicting average indoor temperatures. HEED can predict the highest indoor temperature that is likely to occur with even greater accuracy. However it tends to predict winter indoor minimum temperatures that are colder than will actually occur.

8. SIMULATING HEATING AND COOLING LOADS IN THE TEST CELL IN THE 16 CALIFORNIA CLIMATE ZONES:

Once the validity of HEED was established, then the performance of each test cell could be simulated in each of California’s 16 climate zones.

The test cell was now assumed to have a furnace and an air conditioner with a thermostat that maintained temperatures between 70 to 78°F (21 to 25.5°C), with a night setback as specified by the California Energy Code. Note that these test cells have no internal loads from lights, equipment, and occupants, as would be the case in an actual house. Note also that the data reported here is the load that the building envelope imposes on the HVAC system, which means it does not reflect the performance of that system. This is an example of the difference between loads and energy; the former is determined only by architecture and climate, while the latter couples in the effect of HVAC system performance.

The results show that the absence of internal loads means that the need for heating is exaggerated and the need for cooling is reduced (Fig.6). Notice that In all cases where air conditioning is required, the presence of the external or internal shades reduces the total loads compared to the basecase building. This difference is most pronounced in the climate zones with the hottest summer weather (10 to 15). In all cases both shading strategies performs better than the whole house fan. In El Centro, the hottest desert climate, the automatic shade control functions under heating conditions like an intelligent passive solar collector to reduce furnace loads.

Notice that in California’s coastal climate zones (1, 3, 5, 6, 7) the unshaded basecase building needs very little air conditioning, but in all cases the operable shading system essentially eliminated it entirely.

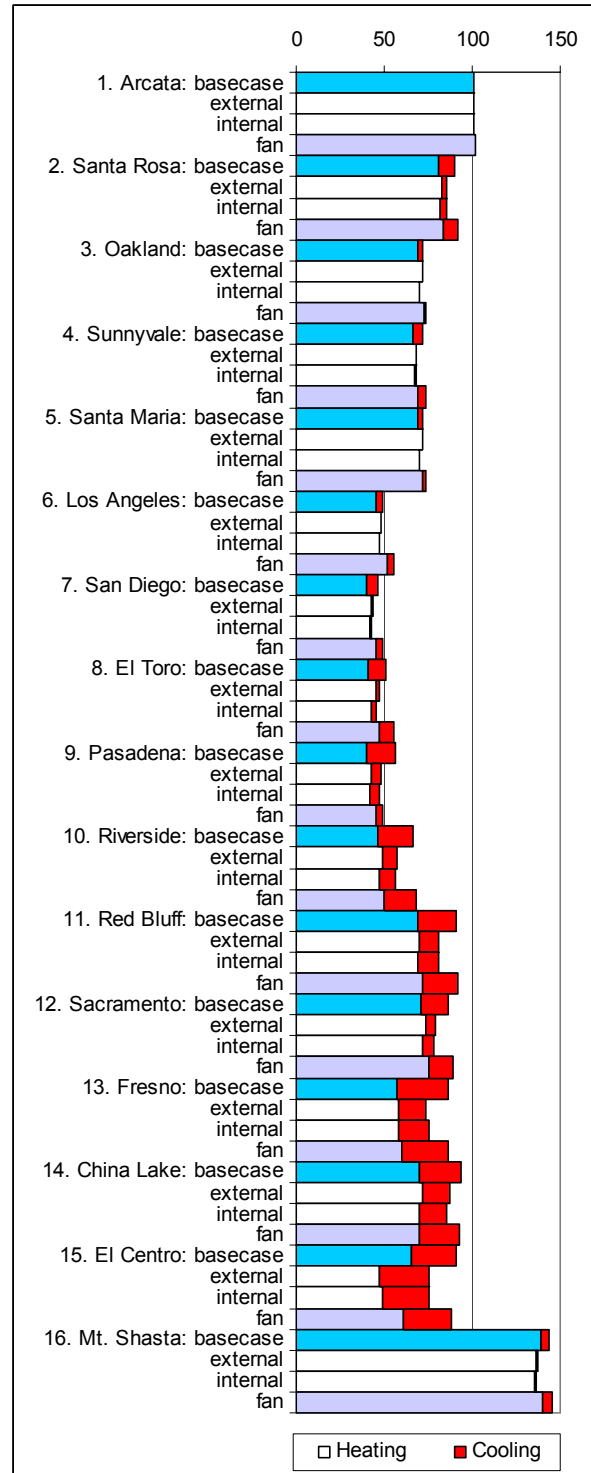


Fig. 6: Heating and Cooling Loads in the Test Cell Simulated by HEED for California’s 16 Climate Zones: for the Basecase Building, External Automatic Sunshades, Internal Automatic Sunshades, and a Whole House Fan.

9. THE PERFORMANCE OF ACTUAL BUILDINGS VS. TEST CELLS

The results of this study again emphasize the limitations of generalizing from experimental data. In the real world actual homes present a huge and complex set of design variables, while the test cell is explicitly designed to minimize the number of design variables.

For example, California's Energy Code specifies different amounts of insulation, different types of glazing, and different maximum window areas for each of the 16 zones. Each climate zone has a different basecase house as defined by the ACM (Alternative Calculation Method), but in all cases it is a low mass building with a square floor plan and the window area distributed equally on each of the four elevations. Obviously this is not the best passive solar design strategy for all of these different climates. In each climate it is quite possible to design a more energy efficient home that uses 20-30% less energy than the basecase design. In fact HEED will automatically design such a house for each climate and latitude.

The test cell used here is not in fact an ACM building. It is 8' by 4', with a four square foot window facing south on the narrow end. The floor was covered by 2.5" bricks to simulate a slab on grade. The interior is sheathed in 1/4" drywall while the exterior is 3" foil faced foam panels. There is an extra layer of foam on the roof, and additional foam panels on 3" spacers are used to shade the exposed east and west walls. The Glazing to floor area ration is 12.5% which is within the 12-16% maximum specified for proscriptive package D in all of California's 16 climate zones.

While it is important to try to reach generalized conclusions based on experimental data, when designing an actual house it is essential to use a simulation tool like HEED that can automatically create the ACM basecase house, then can generate a more energy efficient house, and then can let designers describe their own house in a way that account for all its myriad of unique attributes.

10. CONCLUSIONS:

The results of this series of experiments run in a pair of full-height test cells lead to the following conclusions:

1. Automatic sun shades controlled with a microprocessor that can read outdoor air temperature always performs better than the control cell with an unshaded window.
2. When the shades are placed outside they reduce summer overheating much more than when they are placed inside the experimental test cell, using the same

control rules, but in winter these experimental results reversed, although the differences were small.

3. In summer, experimental results showed that the whole house fan can reduce indoor temperatures better than internal shades but not as well as external shades, however the full set of whole house fan experiments is presented elsewhere (ASES 2002, 2002)
4. Computer simulations of these test cells showed that in all 16 California climate zones the automatic external and internal sun shades reduced total cooling loads.
5. Simulated results confirm that on an annual basis external shades are slightly better than internal, and that both perform better than the whole house fan.
6. Disclaimer: These results were derived from experimental test cells and the performance of actual buildings may differ.

11. RECOMMENDATIONS:

The use of automatic sun shades controlled by an intelligent thermostat that measures both outdoor and indoor air temperatures, can reduce indoor temperatures without assistance of a mechanical cooling system. This will reduce cooling loads in California's warmer climates.

12. REFERENCES

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- (2) La Roche P., Milne M, Effects of Window Size and Mass on Thermal Comfort Using an Intelligent Ventilation Controller, Proceedings of ASES 2003, American Solar Energy Society, Austin, Texas, June 2003
- (3) Milne M., La Roche P., EISG Final Report: Developing a Microprocessor Controller for Automating Residential Sunshades, July 2004

HEED is available at no cost from www.aud.ucla.edu/heed

13. ACKNOWLEDGEMENTS

This project was supported by the Energy Innovations Small Grant (EISG) program from the California Energy Commission.

ⁱ To calculate the performance of closed internal venetian blinds, HEED uses an IAC=.26 (Interior Attenuation Coefficient) described in the 2001 ASHRAE Handbook, 30.48, Table 19. HEED treats exterior louvers in the closed position as an exterior diffuse shade with a SHGC=.13 as defined in the California Alternative Calculation Method (ACM) Table 3-3 CEC Report P400-01-004), and uses the ACM method to combine SHGCs.