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THERMAL PERFORMANCE OF ATTACHED SUNSPACES FOR CANADIAN HOUSES

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ABSTRACT

Based on residential renovation statistics, “sunspaces” are enjoying increasing popularity as Canadian demographics shift toward the elderly and retired. Sunspaces are also becoming common features in new homes. Therefore, energy simulation professionals, designers, and builders will benefit from a better understanding of their behaviour and hopefully avoid practices which may degrade envelope durability, endanger healthy indoor environments, reduce passive solar opportunities, and exacerbate summer cooling loads.

This paper addresses the development of a methodology for using ESP-r software to model the thermal performance of attached sunspaces. The work presented herein forms part of a research project sponsored through the Canadian University Research Network of the CANMET Energy Technology Centre (CETC), Natural Resources Canada (NRCan).

The research involves modeling and analyzing a typical single-family home both with and without an attached sunspace, for several representative Canadian climatic zones. A number of variations in the construction and operation of the sunspace are considered. The orientation of the sunspace, its physical connection to the house, the arrangement of thermal mass, and the aperture and characteristics of the glazing are analyzed. Air movement between the house and attached sunspace, and conditioning of the sunspace are also examined.

The goals of the research project are to identify critical performance parameters for use in the upcoming generation of HOT-3000 software, and to provide guidelines for the appropriate design, construction and operation of attached sunspaces. The paper focuses on a typical “packaged” sunspace and attempts to confirm previous simulation research in this area with the intent of extending the methodology to consider a broader range of sunspace typologies and passive solar heating strategies as the research project progresses.

INTRODUCTION

Attached sunspaces, commonly referred to as sunrooms, represent an opportunity to cost effectively expand the habitable space in a dwelling while affording energy efficiency benefits, provided the sunspace is properly designed, constructed, and operated.

Sunspaces range from unheated, glazed additions resembling porches to fully conditioned spaces integrated with the fabric and mechanical systems of the dwelling. Based on this range of possibilities, Table 1 below outlines the more significant parameters to be considered in a comprehensive assessment of attached sunspace performance.

Performance Simulation Parameters*
Climatic Location
Solar Orientation
Geometry/Aspect Ratio/Size
Thermal Conditioning
Infiltration
Ventilation (natural, mechanical)
Operation (manual/controls)
Communication with Dwelling (inter-zone airflow)
Attachment (thermal bridging)
Fenestration (size, orientation, solar aperture)
Glazing Characteristics (U-value, SHGC, etc.)
Shading
Opaque Envelope U-values
Thermal Mass
*Based on a compilation of parameters considered in previous research work for this area – see references.

Table 1. Significant parameters for performance simulation of attached sunspaces.

In order to perform a comprehensive parametric assessment of sunspace performance, thousands of simulations would be required to address the numerous combinations of variables. Such an exhaustive approach is not possible within the scope of the research program supporting this paper. Instead, a limited set of conventional scenarios is examined according to critical parameters identified by others.

The scenarios examined in this paper represent performance simulations of "packaged" sunrooms widely available through a variety of manufacturers in North America. These are typically considered by homeowners when renovating existing dwellings, or offered by builders as optional upgrades to new homebuyers. The main thrust of this paper is to deal with the initial objectives of the research program:

1. To develop a general approach which can accommodate any attached sunspace simulation scenario; and
2. To test this approach on a conventional sunspace typology.

This assessment of sunspace performance has a special significance for the R-2000 energy efficient house program in Canada. At the time the program was launched in 1983, simulation software was not capable of modelling the complex interactions between the house and attached sunspaces. Crude approximations in the form of energy credits were introduced to reward these passive solar additions. ESP-r now enables a more accurate determination of integrated performance to better deal with the following questions within the context of the Canadian climate and contemporary housing technology:

1. What parameters are critical to the energy performance of sunspaces attached to energy efficient housing?
2. Are differences in the design and construction of attached sunspaces significant between conditioned and unconditioned options?
3. What percentage of the time are unheated sunspaces habitable based on accepted thermal comfort criteria?
4. How energy efficient are conventional sunroom packages compared to contemporary Canadian house construction?

The investigations presented in this paper attempt to build upon and confirm previous work by other researchers studying sunspace performance [1, 2, 3].

METHODOLOGY

The model used for the ESP-r simulations is based on the previous work of Purdy and Beausoleil-Morrison [4, 5], which examined a modern, energy efficient house constructed at the Canadian Centre for Housing Technology (CCHT) in Ottawa, Canada.

The CCHT house comprises two above-grade storeys and a fully conditioned basement. The envelope is of wood-frame construction supported on a cast-in-place concrete foundation. A second storey bedroom is located over an unconditioned garage, separated by an insulated floor assembly. Table 2 summarizes physical characteristics of the CCHT house.

Component	**Area (m2)**	**U-value (w/m2.K)**
Basement Floor	108.4	1.20
Basement Walls	125.8	1.20
Exterior Walls	243.0	0.24
Main Ceiling	146.4	0.37
Floor Over Garage	38.0	0.23
Exterior Doors	9.8	1.0
Windows	22.5	1.90
Total	693.9	0.66
Conditioned Volume – 969.9 m^3 Airtightness - 1.5 ach @ 50 Pa depressurization. Infiltration – 0.09 ach basement, 0.10 ach house		

Table 2. CCHT house characteristics used in ESP-r simulation models.

The house was originally divided into four zones, and for the research presented in this paper a fifth zone was added in the form of an attached sunspace, as depicted in Figure 1.

An important feature of the CCHT house regards its arrangement of fenestration. In Canadian subdivision housing comprised of detached, single-family dwellings, facades between adjacent dwellings are typically provided with minimum window areas, primarily due to privacy considerations. In the case of the CCHT house, there are no windows on the side of the house where the garage is attached. As a result, solar aperture is biased towards the front and rear elevations.

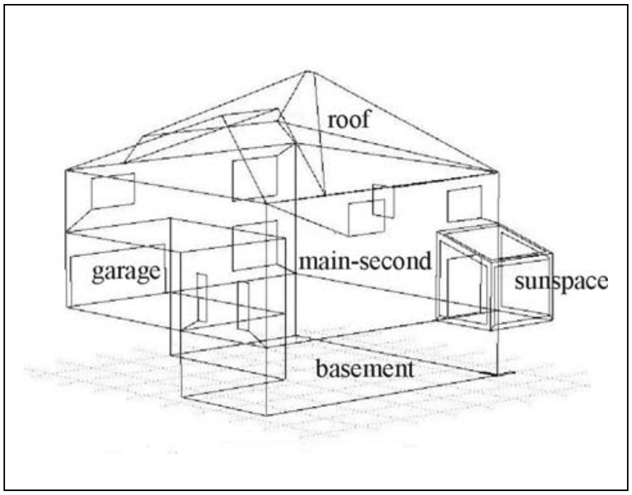
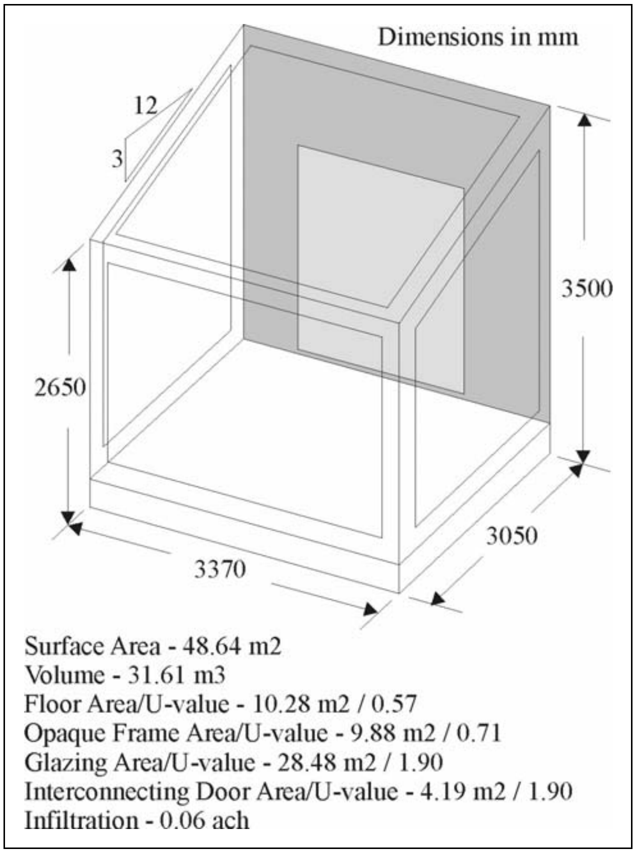


Figure 1. ESP-r model of CCHT house and attached sunspace.



Surface Area - 48.64 m2
Volume - 31.61 m3
Floor Area/U-value - 10.28 m2 / 0.57
Opaque Frame Area/U-value - 9.88 m2 / 0.71
Glazing Area/U-value - 28.48 m2 / 1.90
Interconnecting Door Area/U-value - 4.19 m2 / 1.90
Infiltration - 0.06 ach

Figure 2. Attached sunspace model characteristics.

The sunspace depicted in Figure 2 is for the case where all three sides and the roof are glazed. A second option is also considered where the roof is opaque with a U-value of 0.28 W/m^2.K, inclusive of the roof framing. Additional options are also considered in sensitivity analyses.

The characteristics of the attached sunspace are summarized in Figure 2. It should be noted that the sunspace configuration and characteristics are based on a review of commercially available sunroom packages advertised across North America. The modest size of the sunspace considered in this paper corresponds to basic packages that are intended for use as auxiliary habitable space, often as breakfast rooms or spaces to contain plants.

Based on recommendations for attached sunspace orientation from objective sources [6], the simulations were largely based on a south orientation of the attached sunspace. North, east and west orientations were partially investigated to determine the sensitivity of solar orientation. Each sunspace configuration was located in four Canadian cities with climates representing major population regions of Canada. Table 3 summarizes the climatic data relevant to space conditioning energy demand in buildings.

	Celsius Degree-Days (below 18 ^{o}C)	**Heating Design Temp.**	**Cooling Design Temp.** (dry bulb)
Ottawa	4673	-25.0 ^{o}C	31 ^{o}C
Toronto	4082	-17.2 ^{o}C	31 ^{o}C
Edmonton	5589	-32.0 ^{o}C	28 ^{o}C
Vancouver	3007	-7.0 ^{o}C	26 ^{o}C

Table 3. Canadian simulation locations and corresponding climatic data.

Ottawa is representative of a corridor running eastward to Quebec City and parts of the maritimes. Toronto climatic conditions are representative of the Golden Horshoe and most parts of southern Ontario. Edmonton represents climatic conditions similar to those for most large urban centres in Manitoba, Saskatchewan and Alberta. Vancouver climatic data apply to the lower mainland of British Columbia and most parts of Vancouver Island.

SIMULATION

Simulations of the CCHT house by itself, and then each configuration of the CCHT house with attached sunspace, were carried out using ESP-r, Version 9 Series with Project Manager 4.30a, June 2001 [7].

Climate data files compatible with ESP-r for each of the locations were made available online by NRCan. The heating system setpoints were 18 °C during evenings (8 PM to 8 AM) and 21 °C during the daytime. The cooling system setpoint was a constant 25 °C between May to August, inclusive.

An airflow network was developed to model infiltration for the house and attached sunspace. Leakage openings were sized according to the R-2000 upper limit of 0.07 cm^2/m^2 of envelope surface area. Their location was divided between the lower and upper regions of the house to reflect typical air leakage locations in Canadian house construction. The resulting infiltration rate averaged over the year was 0.09 ach for the house and 0.06 ach for the sunspace. The annual heating and cooling energy demands derived from the airflow network model exhibited good agreement with results obtained using specified infiltration rates in the original CCHT house model developed by NRCan researchers.

Table 4 presents the ESP-r file coding for the simulations and corresponding parameters. There are several parameters appearing in Table 4 that are critical to the simulations.

Operation of an attached sunspace in a cold climate is dependent on seasonality (winter versus summer versus spring/fall), and whether or not the space is conditioned (heating and/or cooling). Cooling of the sunspace was not considered here, in keeping with the assumed scenario of the sunspace being an add-on or upgrade feature.

Operation involves two components of the sunspace – the adjoining door between the house and sunspace, and the use of operable windows in the sunspace. For unheated sunspaces, the tendency for occupants is to keep the adjoining door closed when thermal conditions in the sunroom fall outside of a normative thermal comfort zone.

In the simulations carried out for this paper, the adjoining door is assumed to be open when the sunspace temperature is above 21 °C during the heating season, and closed when the sunspace temperature is above 25 °C during the cooling season.

Code	Description
ccht-	base house model, no sunspace
sun-	base house model with sunspace
S	orientation, S - south
1	1 glazed surface, front wall
2	2 glazed surfaces, front and 1 side wall
3	3 glazed surfaces, front and side walls
4	4 glazed surfaces, walls and roof
1	closed windows, all year
2	"ideal" automatic window operation$^{\Psi}$
3	open windows (May to Aug.)
i	integrated with house envelope
s	separated from house envelope
c	concrete slab-on-grade floor
w	raised wood floor
d	sliding glass door connection to house$^{\Omega}$
u	unheated sunroom
h	heated sunroom (Sept. to Apr.)
ee	300 mm slab, 100 mm insul., glass U = 1.0
o	overhang, 600 mm front, 300 mm sides
Ψ - fully open when $T_{sunspace}$ > 25 °C during cooling season. Ω - fully open when $T_{sunspace}$ > 21 °C during heating season, closed when $T_{sunspace}$ > 25 °C during cooling season.	
Example: sun-S41icdu - base house model with sunspace - sunspace faces south - 4 glazed surfaces, 3 walls and roof - windows closed year-round - concrete slab-on-grade floor - adjoining sliding glass door - sunspace is unheated	

Table 4. ESP-r file coding and corresponding descriptions of simulation parameters.

Three options were considered for the operable windows in the sunspace: closed, "ideal" and open. ESP-r permits the use of controls on apertures such as windows and doors to open and close these according to a variety of control functions. Under the closed option, the windows are never opened and all ventilation is driven by infiltration and convective exchanges with the house, when the adjoining door is open. "Ideal" operation is when the windows are opened whenever the temperature of the sunspace exceeds 25 °C during the cooling season. The open option deals with the case where the windows are open throughout the cooling season, irrespective of sunspace temperature. Each option investigates different phenomena. The closed option attempts to determine how high interior sunspace temperature may climb. The "ideal" option compares how natural ventilation reduces peak temperatures. The open option examines impacts on cooling loads within the house.

RESULTS

Partial results from the simulations for Ottawa are presented in Table 5 where a primary area of interest is the influence of the attached sunspace on the annual heating and cooling demand of the dwelling. Ottawa data is presented in detail because the climate is relatively severe with respect to heating and cooling loads, and is representative of many parts of central Canada where most housing stock resides.

OTTAWA			
File Code	**Heating (kWh)**		**Cooling (kWh)**
	Sunspace	***Total***	***Total***
ccht-S	N/A	13415	3045
ccht-N	N/A	12717	3208
ccht-E	N/A	13528	4209
ccht-W	N/A	13665	4037
sun-S31icdu	0	13487	3215
sun-S41icdu	0	13433	3424
sun-S31icdh	766	14158	3215
sun-S41icdh	1300	14608	3424
sun-S32icdu	0	13532	2869
sun-S42icdu	0	13470	3180
sun-S32icdh	742	14183	2869
sun-S42icdh	1273	14626	3059
sun-S33icdu	0	13602	**2695**
sun-S43icdu	0	13544	2876
sun-S33icdh	742	14252	2695
sun-S43icdh	1273	14693	2876
sun-S32icdu-ee	0	**13115**	2924
sun-S32icdu-o	0	13557	2845
sun-S32icdu-eeo	0	13149	2898
sun-S33icdu-eeo	0	**13220**	**2714**
sun-N32icdu	0	12414	3252
sun-N42icdu	0	12460	3404
sun-N32icdh	1101	13382	3253
sun-N42icdh	1897	14176	3405
sun-E32icdu	0	13243	3961
sun-E42icdu	0	13268	4167
sun-E32icdh	835	13976	3961
sun-E42icdh	1503	14625	4167
sun-W32icdu	0	13434	3633
sun-W42icdu	0	13442	3827
sun-W32icdh	798	14135	3633
sun-W42icdh	1434	14738	3828

Table 5. Thermal performance of attached sunspace configurations in Ottawa, Canada.

Based on the data in Table 5, the most energy efficient orientation of the CCHT house, by itself, is when the rear elevation (where the sunspace is attached) faces north. This is due to the largest glazing areas being located on the front of the house facing south with access to solar gains. The least energy efficient orientation of the house is when the rear faces east, and the largest glazing areas face west causing the highest cooling load.

For unheated sunspaces with a south facing orientation, a reduction in annual space heating demand only occurs when the energy efficiency upgrade is applied to the sunspace envelope. In all other cases the sunspace is not a net solar contributor, however, as it imposes a negligible energy penalty in these cases, it suggests that unheated sunspaces represent a "green" alternative to achieving additional habitable space. In regards to cooling loads, sunspaces with opaque roofs and "ideal" window operation, or sunspaces with windows left open the entire cooling season indicate reductions in cooling load, but also tend to increase space heating energy demand. The best overall performance resulted from a thermally upgraded sunspace having an opaque roof with overhangs, and open windows for the entire cooling season (sun-S33icdu-eeo).

In the case of unheated, north facing sunspaces with conventional envelopes, these proved more energy efficient than their south-facing counterparts. The north facing sunspace acts as a buffer and reduces heat loss through the adjoining glass door during winter, but traps heat to increase cooling load during summer.

Among all sunspace configurations with conventional envelopes, east and west facing, unheated sunspaces delivered the best energy efficiency improvement for the house by buffering against both heat losses and heat gains. The sunspaces with opaque roofs outperform the all-glazed configurations because night-time radiation heat losses are reduced during the heating season, while shading is provided during the cooling season.

Not shown here are results for sunspaces with an insulated, raised wood floor (low thermal mass) versus the insulated concrete slab-on-grade. The difference in performance was negligible due to the higher thermal resistance of the wood floor, and the relatively small area and depth of the concrete.

For heated sunspaces with conventional envelopes, regardless of orientation, the annual space heating demand per unit floor area is significantly higher than for the house. Opaque, insulated roofs are more energy efficient than glazed roofs, but even in the case of the upgraded sunspace (results not shown here), the house provides more energy efficient habitable space. This relationship underlines the benefits of high levels of thermal insulation and airtightness in R-2000 homes.

Table 6 summarizes space conditioning energy demand for a select number of sunspace configurations for each of the other climatic locations investigated in the research: Toronto, Edmonton and Vancouver. Only unheated, south-facing configurations were considered. It should noted that some of what may appear to be anomalous results are due to the insolation data contained in the weather files, which reflect actual climatic differences (i.e., how sunny the winter, how cloudy the summer).

File Code	**Heating (kWh)**	**Cooling (kWh)**	**Total (kWh)**
TORONTO			
ccht-S	12079	3198	15277
sun-S32icdu	12063	3005	15068
sun-S42icdu	12010	3195	15205
sun-S33icdu	12120	2848	14968
sun-S43icdu	12065	3030	15095
sun-S32icdu-eeo	11643	3008	14651
sun-S33icdu-eeo	11702	2841	14543
EDMONTON			
ccht-S	15404	2152	17556
sun-S32icdu	15567	1925	17492
sun-S42icdu	15550	2073	17623
sun-S33icdu	15748	1752	17500
sun-S43icdu	15726	1889	17615
sun-S32icdu-eeo	15044	1925	16969
sun-S33icdu-eeo	15232	1746	16976
VANCOUVER			
ccht-S	8571	2840	11411
sun-S32icdu	8505	2586	11091
sun-S42icdu	8487	2789	11276
sun-S33icdu	8568	2358	10926
sun-S43icdu	8549	2551	11099
sun-S32icdu-eeo	8176	2606	10781
sun-S33icdu-eeo	8241	2368	10609

Table 6. Thermal performance of selected, south-facing sunspace configurations in Toronto, Edmonton and Vancouver, Canada.

Looking at the overall pattern for these other climatic locations, unheated, south-facing sunspaces continue to represent "green" alternatives for habitable space. Returning to Table 5, it is observed that that improvements in overall, annual energy efficiency range from 1.0% for conventional sunspace construction to 3.2% for energy efficient configurations. Based on the data in Table 6 for the other climatic locations, the respective relationships are as follows: Toronto, 2.0 to 4.8%; Edmonton, 0.3 to 3.3%; and Vancouver, 4.3 to 7.0 %.

Table 7 examines dry bulb temperature frequency ranges for a selected number of sunspace configurations in each of the Canadian climatic locations considered in the research: Ottawa, Toronto, Edmonton and Vancouver.

	Temperature Range Frequency (%)	
File Code	**< 18 °C**	**> 28 °C**
OTTAWA		
sun-S32icdu	17.7 (-2.4)	19.1 (69.2)
sun-S42icdu	23.1 (-4.3)	20.5 (77.9)
sun-S32icdu-eeo	9.0 (7.4)	39.6 (84.2)
sun-S33icdu-eeo	28.2 (0.2)	34.7 (84.2)
TORONTO		
sun-S32icdu	24.5 (0.6)	19.5 (63.8)
sun-S42icdu	29.5 (-1.1)	20.7 (73.5)
sun-S32icdu-eeo	8.5 (7.0)	39.1 (75.5)
sun-S33icdu-eeo	26.8 (0.4)	34.3(75.5)
EDMONTON		
sun-S32icdu	33.8 (-13.0)	16.1 (66.9)
sun-S42icdu	38.6 (-17.0)	15.7 (73.3)
sun-S32icdu-eeo	18.5 (-3.4)	31.8 (80.9)
sun-S33icdu-eeo	44.6 (-3.4)	28.5 (80.9)
VANCOUVER		
sun-S32icdu	17.8 (3.3)	19.0 (72.7)
sun-S42icdu	23.0 (1.4)	18.4 (80.4)
sun-S32icdu-eeo	6.2 (9.7)	36.2 (88.5)
sun-S33icdu-eeo	34.8 (3.8)	32.6 (88.5)
Values in parentheses ( ) indicate minimum and maximum temperatures predicted in the sunspace.		

Table 7. Annual frequency of uncomfortable dry bulb temperatures in sunspace – Ottawa.

In examining the data in Table 7 it should be noted that for temperature frequency ranges below 18 °C, a large proportion of this period occurs during the evening hours when there is no benefit from insolation. Conversely, temperature ranges above 28 °C occur exclusively during daytime hours.

The data indicate that for conventional sunspaces, temperatures can fall below freezing for locations except Vancouver, but these configurations tend to experience smaller frequencies of temperatures above 28 °C. Energy efficient sunspaces provide better thermal comfort during the heating season, but exhibit a "greenhouse effect" during summer months. In the case of the conventional sunspace with a glazed roof, an interesting difference may be noted between Ottawa and Toronto versus Edmonton and Vancouver with respect to overheating in summer. Night-time radiation cooling effects are more pronounced in warmer and colder climates.

CONCLUSIONS

Based on the limited scope of this paper, the following conclusions can be made regarding the performance of packaged sunspaces attached to contemporary Canadian houses:

1. Viewed from a house-as-a-system perspective, the orientation of the principal fenestration areas of the house is more significant than room-sized sunspaces with respect to passive solar heating potential.

2. Direct gain approaches to passive solar heating are more efficient than conventional sunspaces, and only marginally less effective when the sunspace envelope is highly energy efficient. This confirms previous work in this area [8].

3. Sunspaces with overhead shading devices or opaque roofs, open to natural convection during the cooling season resemble the behaviour of double-skin facades.

4. For the south facing sunspace to be effective, the thermal mass of the concrete slab must be increased, insulation levels beneath the slab and its edges must be increased, the glazing must be more efficient and shading devices must be incorporated into the glazed roof to capture and reject solar gains as required. Proper operation of the sunspace and interconnecting apertures is also critical.

5. Previous research in this area has been reinforced – overheating remains a major problem unless adequate shading is provided.

The research supporting this paper will continue to examine a variety of parameters and configurations that remain to be investigated. In particular, the size and glazed area of attached sunspaces, glazing characteristics, shading devices and integration with mechanical systems.

At this point, it may be concluded that only unheated, conventional sunspaces make sense in a cold climate from an energy efficiency perspective. The large variation in sunspace temperatures suggests an examination of material degradation problems may be warranted. Heated sunspaces may require more sophisticated design and systems integration which may ultimately prove to be better allocated to the design of a whole-house direct-gain system.

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REFERENCES

1. Bakos, G.C and Tsagas, N.F. (2000), *Technology, Thermal Analysis and Economic Evaluation of a Sunspace Located in Northern Greece*, Energy and Buildings 31, pp. 261-266.

2. Mihalakakou, G. and Ferrante, A., (2000), *Energy Conservation and Potential of a Sunspace: Sensitivity Analysis*, Energy Conversion and Management 41, pp. 1247-1264.

3. Gonçalves, H.P., Oliveira, M.N. and Patricio, A.M, (1997), *The Use of a Simulation Tool to Obtain the Thermal Performance of Passive Solar Houses in Portugal*. Proceedings of Building Simulation '97, Volume 2: 371-378.

4. Purdy, J. and Beausoleil-Morrison, I. (2001), *The Significant Factors in Modelling Residential Buildings*, Proceedings of the Seventh International IBPSA Conference on Building Simulation, 13-15 August 2001, Rio di Janeiro, Brazil.

5. Purdy, J. and Beausoleil-Morrison, I. (2001), *The Significant Factors in Modelling Residential Buildings: Part 2*, Proceedings of eSim 2001, Canadian Conference on Building Energy Simulation, 13-14 June, 2001, Ottawa, Canada.

6. U.S. Department of Energy (1994). *Sunspace Basics*. www.eren.doe.gov/erec/factsheets/sunspace.html (Nov 1994).

7. ESRU (2000), *The ESP-r System for Building Energy Simulations: User Guide Version 9 Serie*s, ESRU Manual U00/1, University of Strathclyde, Glasgow UK.

8. Lucas, I.B. and Hoesé L. and Ponoriero, D., (2000), *Experimental Study of Passive Systems Thermal Performance*, Renewable Energy 19, pp. 39-45.