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AN ENERGY AND ECOLOGICAL ANALYSIS OF ALTERNATE RESIDENTIAL LANDSCAPES

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ABSTRACT

A number of recent studies suggest the use of vegetative landscaping to reduce heat gain by a residential structure during the cooling season, thereby significantly reducing the energy used for air conditioning. In order to determine overall energy savings, energy consumed in maintaining the residential landscape should be considered. This study has included an energy flow analysis of alternate residential landscapes in a manner similar to that typically done on natural ecosystems. In particular, energy inputs and flows involved in the purchase, installation and maintenance of various combinations of lawn, shrubs and trees have been analyzed. This analysis, along with calculated investment ratios, indicates which landscape designs and practices will minimize fossil fuel inputs, best utilize natural energy flows and minimize negative ecological impacts.

INTRODUCTION

A number of studies have been made which analyze the potential use of vegetative landscaping for residential energy conservation [1-5]. Some studies [1, 2] have indicated that vegetative windbreaks can reduce heating requirements of a residence in the midwest by 23 to 34 per cent by decreasing cold air infiltration during the heating season. Another recent analysis has documented a 58 to 65 per cent reduction in the energy used to air condition a double-wide mobile home during some very warm summer days in Miami, Florida [5]. In order to determine the overall energy savings associated with the use of vegetative landscaping, one should take into account the energy consumed in the installation and maintenance of that landscape. An energy analysis of a residential landscape should yield information regarding the energy inputs and

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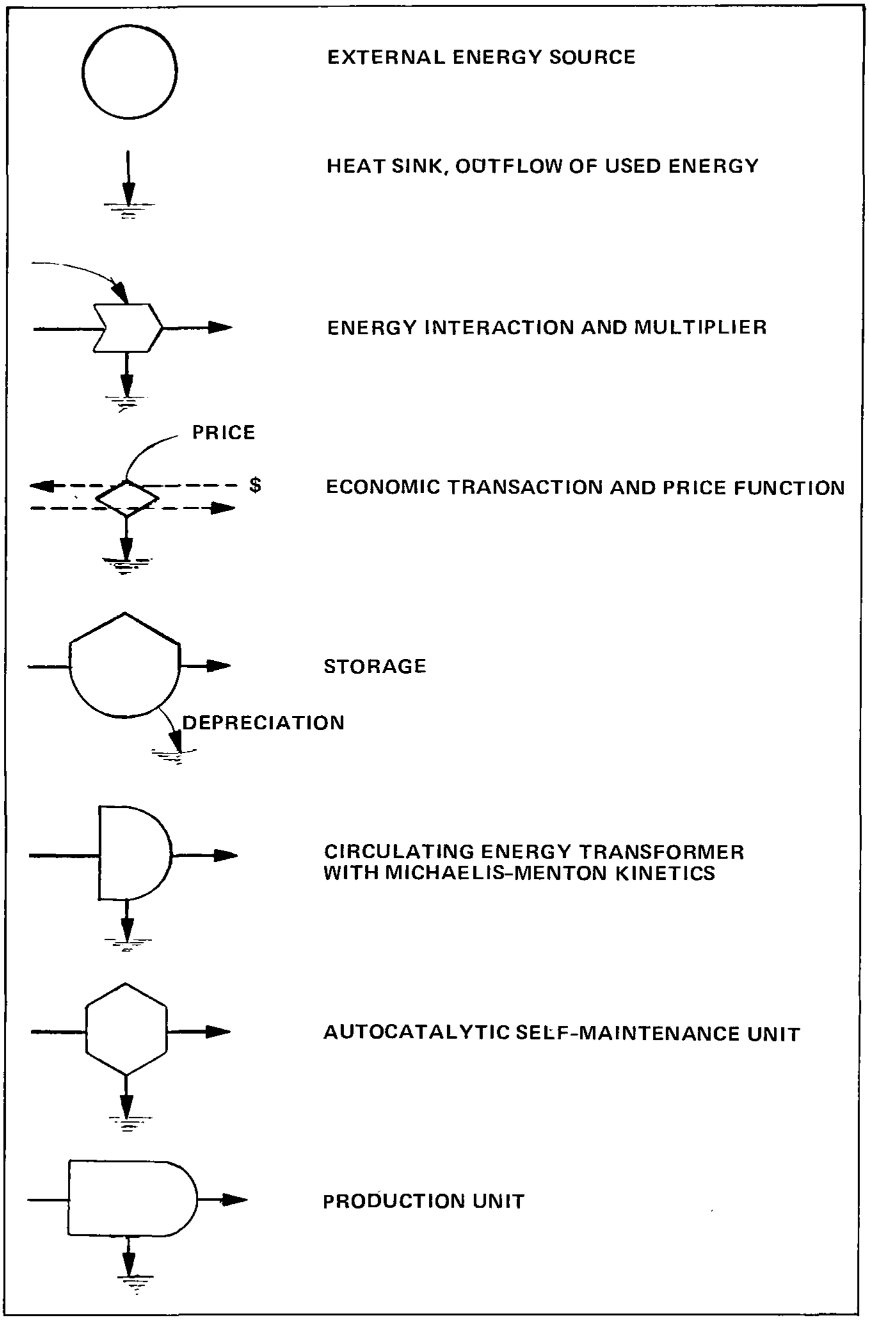

Figure 1. Energy circuit symbols.

the important energy interactions between a residence, its occupants and the vegetative landscaping. Furthermore, the information obtained can be utilized in the development of the important characteristics of an optimal energy conserving landscape design. Operational and maintenance practices which are most appropriate should be revealed.

An investigation of the energy flows of an ecosystem is a common undertaking in the field of ecology. The energy analysis methodology is usually applied to a natural system rather than a man-created environment, although Falk has studied the energetics of a small suburban lawn in California [6]. That study showed energy inputs equaling or exceeding that used in corn production and comparable net productivities.

This paper will include energy analyses of various alternate residential landscapes. In order to facilitate quantitative comparisons, data appropriate to a Florida site have been utilized. Energy circuit models as described by Odum and Odum have been used to illustrate the characteristics of alternate landscape designs and the symbols used are shown in Figure 1 [7].

ENERGY MAINTENANCE INPUTS

In order to do an energy analysis of residential landscapes, one must estimate the direct and indirect energy or "fossil fuel" inputs used in maintaining the various elements of the vegetative landscape: the trees, the shrubs, and the lawn. Determining the precise values for these inputs is impossible because of the extreme variations in maintenance practices associated with various vegetative species and systems. Nevertheless, cost estimates, coupled with data on the energy intensities of the various materials used [8] can at least reveal approximate values for typical requirements of vegetation commonly used in a Florida landscape.

In general, the plants in a residential landscape will require extensive amounts of fertilizers, pesticides, herbicides, irrigation water and gasoline for the lawn mower. In this analysis, the amounts of these materials utilized are estimates based on the operational practices recommended in Florida Agricultural Extension Service Bulletins. The amount of irrigation water needed was determined by estimating the amount required to supplement normal rainfall. The amount of pesticides required corresponds to that recommended in *preventive* maintenance.

The annual dollar and energy costs of the materials used in the maintenance of a medium size (1.5m tall) shrub is shown in Table 1. Perhaps the most surprising conclusion from this data is the relatively small dollar and energy costs of fertilizer. In most energy analyses of agricultural systems, the largest indirect energy input is fertilizer since it is quite energy intensive and is in fact a direct product of fossil fuels. However, the data for the residential landscape indicate that there is a larger input via irrigation and pesticide use.

Table 1. Annual Dollar and Energy Costs for the Maintenance of a Shrub

	Dollar Costs ($)	*Energy Intensity (BTU/$)*	*Energy Costs (BTU)*
Fertilizer	0.05	174,000	8,700
Water	0.25	108,000	27,000
Pesticide	0.75	168,000	126,000
	$1.05		161,700

There are a number of reasons for this different result in the case of a residential landscape. Typically, the landscape plants are fertilized only at the level required for health and moderate growth, and not to maximize production as in agriculture. The input from water use in the residential landscape is large primarily because water which is treated and supplied by a utility is much more energy intensive than that typically used in agriculture. The extremely high energy cost associated with pesticide use arises because of the energy intensity of the pesticide itself and because of the extensive amounts used in a preventative maintenance program. Clearly, an important consideration in energy conserving landscape design is the use of disease resistant plant species. Also, pesticides should generally be applied only in response to specific plant disease problems, not as a preventive measure.

It is a common assumption in energy conservation landscape design that the most energy intensive sector of the landscape is the lawn. In fact, an often suggested approach for reducing the indirect energy inputs of a landscape is to replace the lawn or at least reduce it using other vegetation such as trees and shrubs. In order to compare the energy intensities of the various types of vegetation, it is helpful to do energy analyses for lawns and trees similar to that described above for shrubs. In order to put the comparison on a common footing, the energy consumed should be calculated on a per square meter basis. The results of this type of analysis are shown in Table 2. The energy consumed in the form of gasoline for mowing has been included for the lawn.

Table 2 shows that as is the case for the shrub, there is more energy input through irrigation and pesticide spraying of a lawn than via fertilizing. It should be noted that although the use of gasoline in mowing the lawn is the only *direct* fuel consumption, its total energy contribution is quite small compared to the other sources. The energy consumed through watering is the same for all three types of vegetation since the recommended irrigation rates are approximately the same. The most interesting observation with regard to Table 2 is that *on a per square meter basis*, a lawn is *less* energy intensive than either a shrub or a five-year-old tree. Consequently, simply replacing lawns with trees and

Table 2. Annual Indirect Energy Costs per Square Meter for Lawns, Shrubs, and Trees in a Florida Landscape (BTU per Square Meter)

	Lawn	*Shrub*	*Tree (5 Years Old)*
Fertilizer	3,500	5,800	22,600
Water	18,400	18,400	18,400
Pesticide	6,700	84,600	42,000
Gasoline	1,300	–	–
Total	29,900	108,800	83,000

shrubs can actually *increase* the indirect fossil fuel inputs into the residential landscape. As noted before, the major reason for this lies in the high energy inputs associated with the preventive pesticide spraying of a shrub or a small tree. By carefully selecting shrubs and trees which are fairly disease and drought resistant and which are appropriate to the specific climate and soil of the site, one can reduce these indirect energy inputs to only a small fraction of that shown in Table 2. For example, a native Florida shrub such as wax myrtle (*Myrica cerifera*) which is established (after a two- or three-year period), does not require preventive spraying, usually needs only normal rainfall, and fixes its own nitrogen. Consequently, it could be maintained with annual indirect energy inputs of about 1800 BTU per square meter, an energy intensity much lower than for the lawn. Likewise, other native trees and shrubs, when planted in appropriate soil and climate conditions, may not require any of these indirect fossil fuel inputs once they are well established.

COMPREHENSIVE ENERGY ANALYSIS

The analysis in the previous section does indicate which types of landscape maintenance inputs are most energy consuming. However, an even more complete picture would include the energy inputs associated with all aspects of the residential landscape such as the energy embodied in purchasing the plants, in the tools and in the labor involved. Although the precise energy amounts associated with these entities are difficult to document, Odum and Odum have found that for many goods and services in the U.S. economy, there is a fairly constant ratio of dollars to energy: about 80,000 BTU per dollar [7]. Using this value, one can estimate the energy inputs of these additional factors for a typical residential landscape in Florida.

In order to derive an estimate of these energy inputs, it is also necessary to make a number of simplifying assumptions:

Table 3. Annual Indirect Energy Costs per Square Meter—with All Goods and Labor Included—for Lawns, Shrubs and Trees in a Florida Landscape (BTU per Square Meter)

	Lawn	*Shrub*	*Tree (5 Year)*	*Tree (10 Year)*
Purchase	4,000	7,200	5,600	2,400
Fertilizer	3,500	5,800	22,600	–
Water	18,400	18,400	18,400	–
Pesticide	9,900	106,200	63,600	–
Mowing/Pruning	15,200	–	–	–
Herbicide	1,200	–	–	–
Tools	2,400	13,600	6,400	2,400
Mulch	–	22,400	–	–
Total	54,600	173,600	116,600	4,800

1. It is assumed that someone is hired to mow the lawn and to periodically spray the vegetation to prevent the infestation of plant diseases or pests.
2. Labor typically done by the homeowner (such as watering, fertilizing and pruning) is not included since it is an internal input with extremely great variability.
3. It is assumed that the landscape will include forty shrubs and ten trees.
4. A thirty-year lifespan for the vegetation is assumed in determining the annual costs associated with the initial purchase of the plants and lawn.
5. After a five- to seven-year establishment period, the trees are no longer fertilized, watered or sprayed.
6. The energy inputs associated with the commercial trimming and pruning of large trees for storm protection or because of interference with power lines, etc., has not been included. Although these inputs may be substantial, there are too many uncertainties to allow for quantitative comparisons.
7. The indirect energy inputs associated with sophisticated and/or expensive maintenance tools such as riding mowers and power hedgers can be very large. However, due to the wide variability in their use and price they have not been included. Only common maintenance tools have been included.

A summary of the indirect energy inputs estimated using these assumptions is shown in Table 3. As in Table 2, the energy inputs are calculated on a per square meter basis to facilitate comparisons. The inclusion of a more comprehensive list of energy inputs does not appreciably alter the relative energy intensities of lawns and typical trees and shrubs. Although a significant energy input is made in the mowing of the lawn, this is more than offset by the energy inputs from using purchased mulch around the shrubs. Also, it should be noted that the lower energy input to the lawn via tools is due to the large number of square meters of lawn over which the tool expenditures are averaged. The data in Table 3 clearly indicate that a well established tree which is healthy and does not require extensive periodic pruning is the least energy intensive of the various types of vegetation.

COMPARISON OF ALTERNATE RESIDENTIAL LANDSCAPES

Energy conservation landscapes typically include the use of trees, shrubs and a lawn. Obviously, a residential landscape consisting only of an extensive lawn would allow very large amounts of solar radiation to impact on the house. Also, previous studies [3-5] have verified that the appropriate placement of trees and shrubs near a residence can substantially reduce the energy consumed in air conditioning in a warm, humid environment. However, the energy analysis of the previous section has indicated that the addition of trees and shrubs can potentially require significant additional energy maintenance inputs. This is an important consideration since these indirect energy inputs can offset a significant portion of the air conditioning energy savings associated with the landscaping. Figure 2 shows an energy model of a residential landscape which illustrates the complex web of interactions between the house, the residents, the local economy and the landscape. The variety of indirect energy inputs which go into the maintenance of the vegetation is readily apparent. In order to investigate these interactions in greater detail and in order to determine methods of minimizing the energy maintenance inputs, this section will compare three alternate landscape designs for a residential site with a one-quarter acre landscape area:

1. a “lawn” landscape;
2. an “energy conservation” or ecological landscape (e.c.); and
3. an “urban forest” landscape.

Lawn Ecosystem

The first landscape to be analyzed consists of a quarter-acre lawn surrounding a residence in a Florida suburb. A schematic of this system is shown in Figure 3

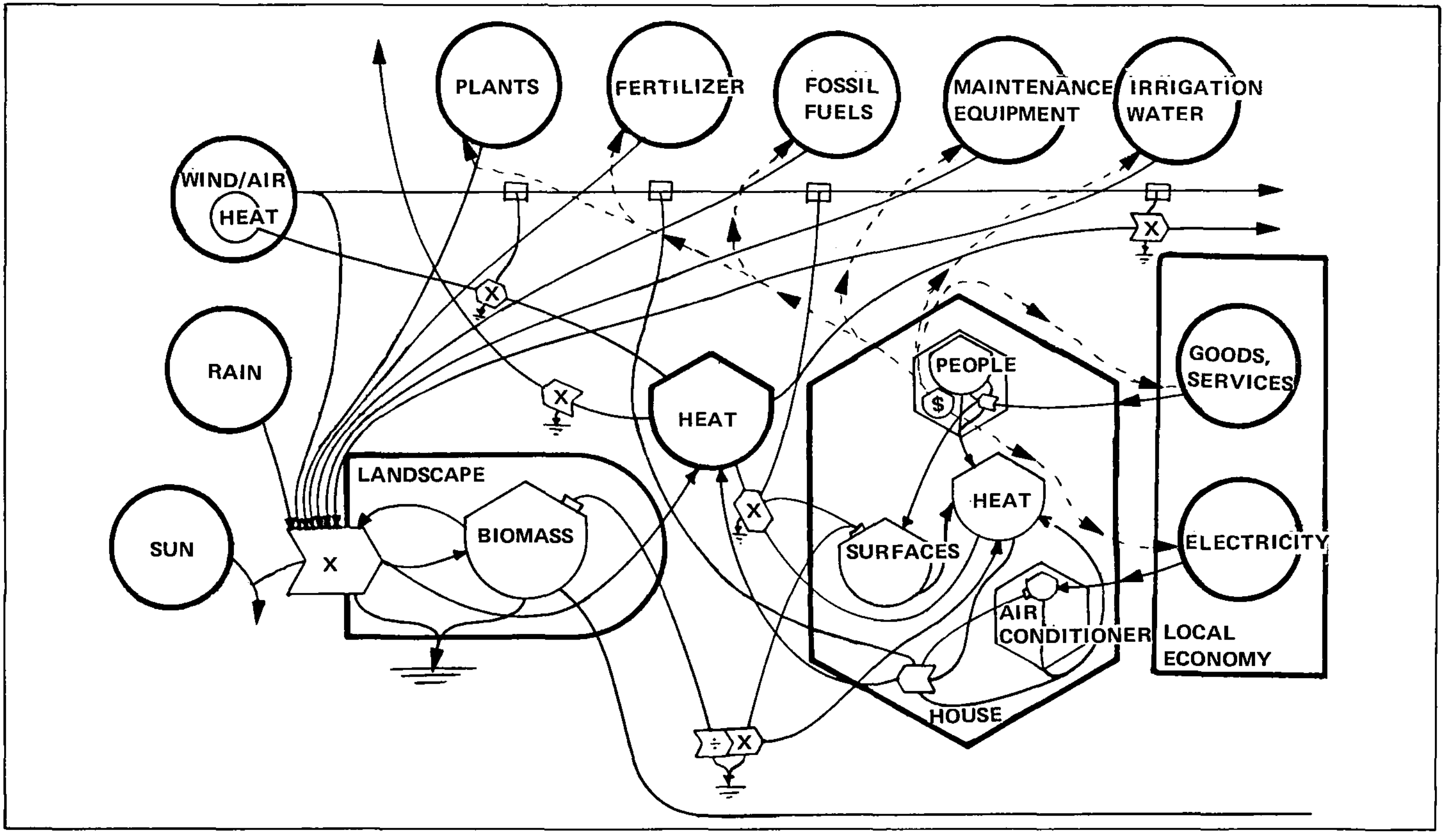

Figure 2. Energy model of a residential landscape.

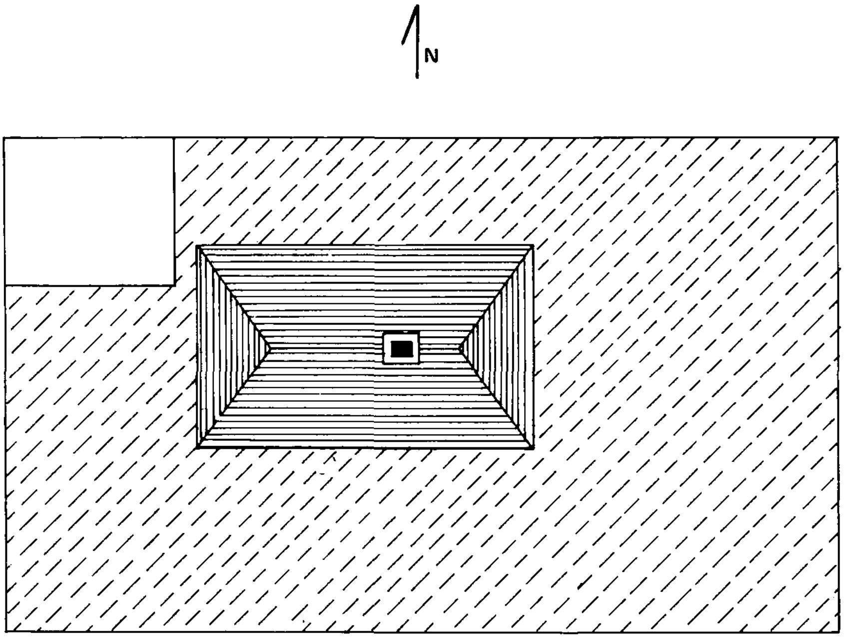

Figure 3. The "lawn" landscape.

while an energy model of the ecosystem is shown in Figure 4. The energy model illustrates a number of important characteristics of the lawn ecosystem. Large energy inputs are made to the lawn from both natural and cultural sources. The grass production system is very analogous to an agricultural photosynthesis system which produces foodstuffs for animal or human consumption. However, it is noteworthy that the major product of the lawn ecosystem is lawn clippings. This cultivation product, in contrast to agricultural products, is not typically utilized in any manner. However, it does consume additional fossil fuels by becoming a solid waste output requiring collection and disposal by the external system in exchange for money from the resident. Obviously, the attributes of a typical suburban lawn lies not in its product cuttings but rather in its aesthetic and recreational value.

Another observation from the energy model is that a lawn may contribute significant pollutants to the local environment, particularly local water resources, through runoff containing pesticides, herbicides, and fertilizers. In suburbs containing large numbers of residences with extensive lawns, the cumulative pollution from these "non-point" sources can be quite large. In locales where groundwater is close to the surface and is the major source of municipal water supply (such as in south Florida), this type of pollution may be of particular concern. Although similar pollution from agricultural sources is

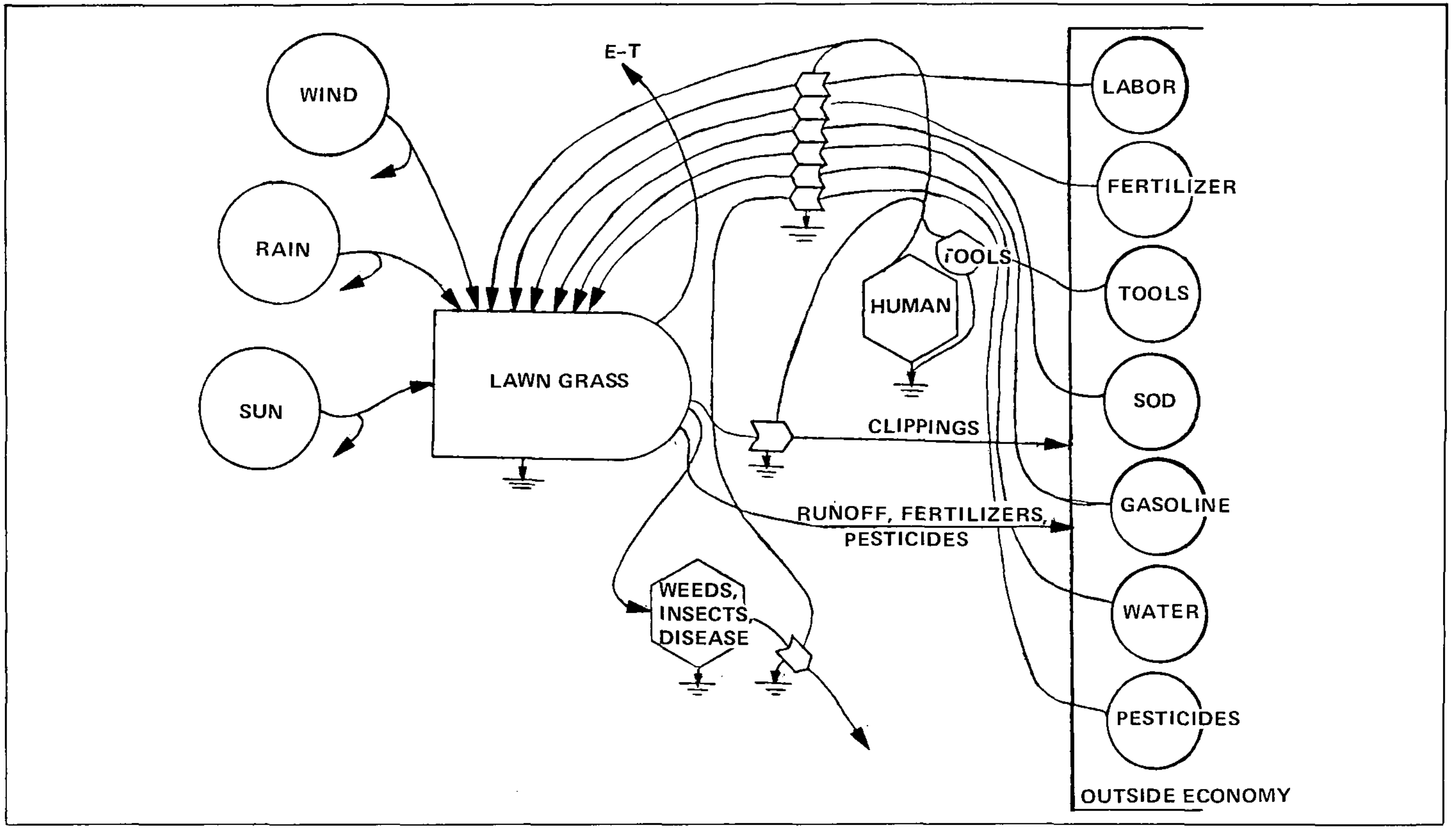

Figure 4. An energy model of the "lawn" landscape.

routinely monitored and controlled, that from residential landscapes is rarely noted and never regulated.

The Energy Conservation Landscape

The energy conserving or ecological landscape plan is shown in Figure 5 with the corresponding energy model shown in Figure 6. This design incorporates concepts and operational modes which minimize the consumption of resources as well as negative impacts on the environment. Listed below are the major characteristics of the e.c. landscape including the ways in which it differs from the lawn landscape.

1. All but one-sixteenth of an acre of the lawn is replaced by trees, shrubs and ground cover.
2. The remaining lawn is fertilized and mowed less often.
3. A number of trees and shrubs are positioned fairly close to the residence, primarily on the east, west and south sides, to provide significant shade for the windows and walls.
4. The plants used are generally native species which are fairly disease and drought resistant.

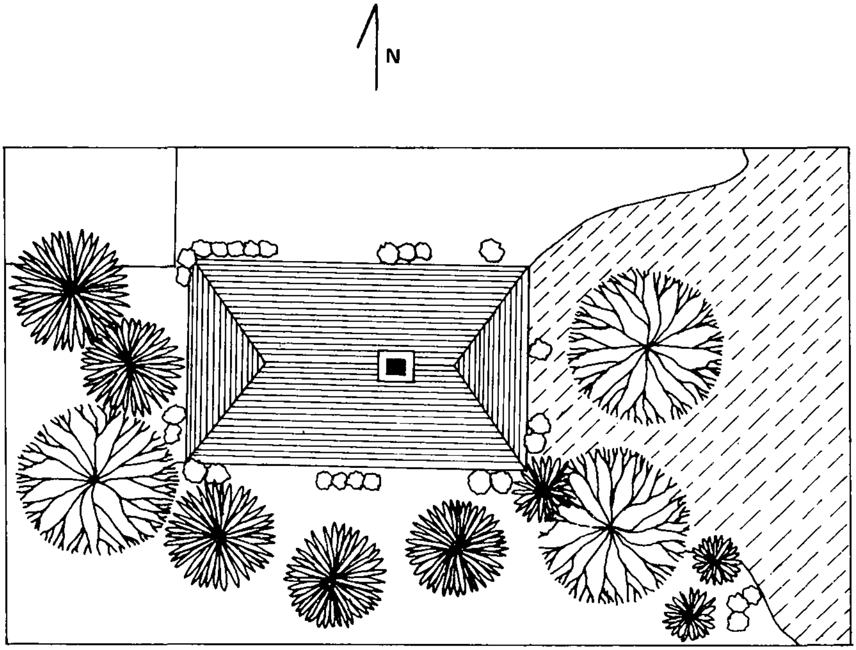

Figure 5. The "energy conservation" landscape.

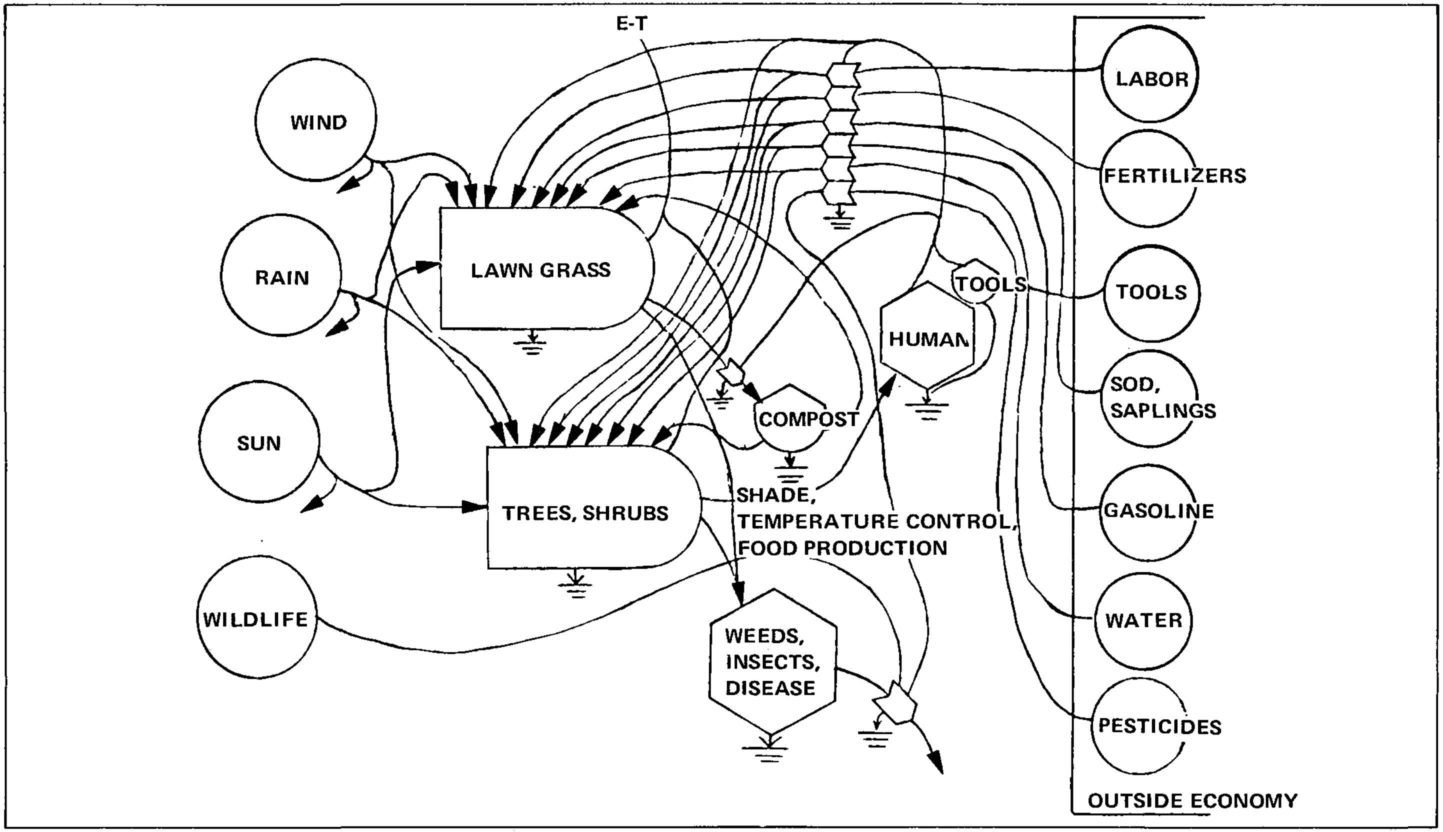

Figure 6. An energy model of the "energy conservation" landscape.

5. The following water conservation techniques are practiced.
    - Irrigation is done less often and "deep" to encourage vertical root growth and, after a five-year established period, is only done at early signs of wilting.
    - "Precision" sprinkling procedures such as watering during cool, calm periods and slow drip irrigation are employed to minimize runoff and evaporation losses.
    - Only minimal amounts of fertilization is done before and during the dry season to minimize water requirements during that period.
    - Deciduous species which are leafless during the dry season are used where appropriate, thereby requiring less watering during that period.
    - All trees and shrubs are extensively mulched. This practice aids in moisture retention, particularly during the dry season.
6. Pesticide spraying is done only when pests or a disease are actually detected.
7. No herbicides are used.
8. Normally recommended amounts of fertilizer are applied to the trees and shrubs for the first five years to maximize growth and securely establish the plants.
9. All grass cuttings, leaves and other plant trimmings are utilized for composting and mulching.
10. The pruning requirements of the trees and shrubs are minimized by proper spacing, positioning and species size selection.
11. Some of the trees utilized are low maintenance fruit trees for food production.
12. A small vegetable garden is established in a sunny area away from the residence.

The total annual energy maintenance requirements for the lawn and energy conservation landscapes are shown in Table 4. They have been calculated from the energy input values determined in the previous section but with modifications due to the conservation practices described above. The data confirm that the careful gardening and conservation procedures utilized for the e.c. landscape have dramatically reduced the energy maintenance requirements for trees and shrubs. The e.c. landscape consumes only about one-fourth the fossil fuel consumed by the lawn system while providing significant reductions in the energy used for cooling the residence. Most of the savings are associated with reductions in irrigation and pesticide requirements through the use of water conservation techniques and by selecting drought and disease resistant trees and shrubs. Also, the recycling of lawn clippings, leaves and other trimmings significantly reduces the fertilizer, purchased mulch, and water requirements of the trees and shrubs.

Table 4. Annual Indirect Energy Costs for the "Lawn" Landscape and the "Energy Conservation" Landscape. Both are One-Quarter Acre in Size

	Average Energy Costs per Square Meter (BTU/M^2)	*Total Energy Costs (BTU)*
Lawn Landscape	5.5×10^4	5.6×10^7
Energy Conservation Landscape	1.4×10^4	1.4×10^7

An advantage of the energy conserving landscape which is not apparent from the data is the flexibility in its water requirements during an extended drought such as the ones experienced in Florida in 1972 and 1981. Under severe drought conditions, only the small lawn area would require irrigation to insure survival. Furthermore, the amount of irrigation per square meter of lawn required for survival would be significantly less in the e.c. landscape. Less frequent watering of the grass would be possible because of 1) the deeper root growth and 2) tree shading which reduces solar insolation on the grass and thus lowers soil evaporation rates. Also, the fact that the non-lawn sections of the landscape would typically require only minimal watering during the dry season reduces "peak" water demands. Consequently, the need to expand water supply systems in the future is reduced.

Energy Investment Ratios

In energy analysis, a method often used [7] to compare alternate systems is to determine their energy investment ratios (I) defined as follows: I = fossil fuel inputs/natural energy inputs. This ratio may reveal insights as to whether the system is structured to optimize the utilization of natural energy in conjunction with fossil fuel feedback energies.

The major natural energy inputs to a lawn ecosystem are incident solar radiation and rain. Average solar radiation in Florida is equivalent to 1.6×10^6 solar calories/m^2/yr. Thus a quarter acre lawn would receive 1.6×10^9 solar calories/yr. Utilizing the chemical and impact energies [9] of pure rain, the 55 inches of rain which typically falls in Florida corresponds to an energy input of 3.8×10^6 solar calories/m^2/yr or 3.8×10^9 solar calories/yr for the quarter acre. Natural energy inputs associated with the wind are about 0.5×10^9 solar calories/yr so the total natural energy input to the one-fourth acre is 5.9×10^9 solar calories per year. For the lawn and e.c. landscapes, the natural energy inputs would be fairly similar while the fossil fuel inputs differ as shown in Table 4. When these values are converted to solar calories, investment ratios can be calculated. The investment ratio calculated for the lawn system, 4.4, is comparable though higher than that observed for most U.S. processes, 2.5 [7]. The much lower investment ratio for the ecological landscape, 1.1, indicates that in a period of declining fossil fuels, it will make more efficient use of those non-renewable resources and thus will be a more competitive system.

The Urban Forest Landscape

A third alternate landscape which can be compared to the two previously described systems is the "urban forest" system which is shown in Figures 7 and 8. This system would differ from the e.c. landscape in the following ways:

1. the quarter-acre would be totally covered by a multiple-canopy forest of native trees with shade tolerant native shrubs and ground cover underneath;
2. after a three- to five-year establishment period, the trees, shrubs and ground cover would no longer be sprayed, fertilized or irrigated; and
3. only minimal maintenance involving the removal of exotic invader species and the selective pruning of diseased or decayed limbs would be done.

Clearly, the urban forest landscape would require only very minimal amounts of fossil fuel inputs and would provide very large reductions in the energy used in air conditioning. In addition to a reduction in labor for landscape maintenance, the major advantage of this system over the e.c. landscape would be the providing of appropriate habitat for small wildlife in a naturalistic setting.

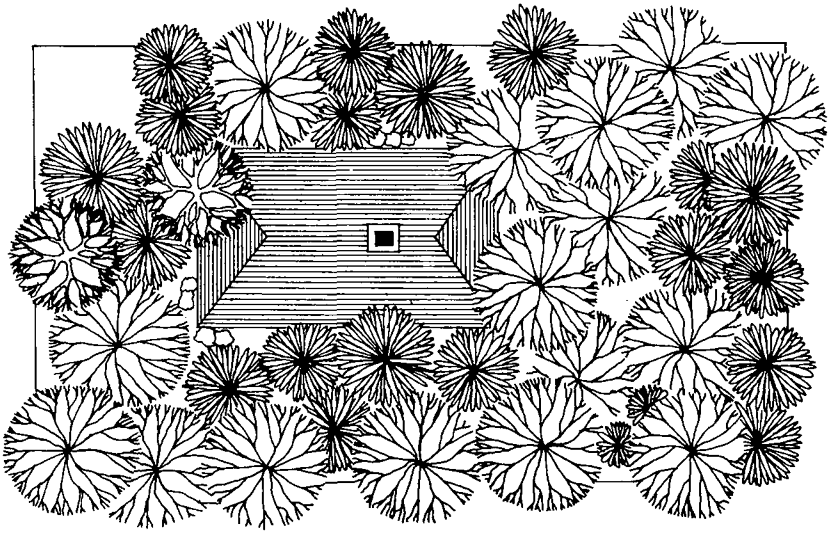

Figure 7. The "urban forest" landscape.

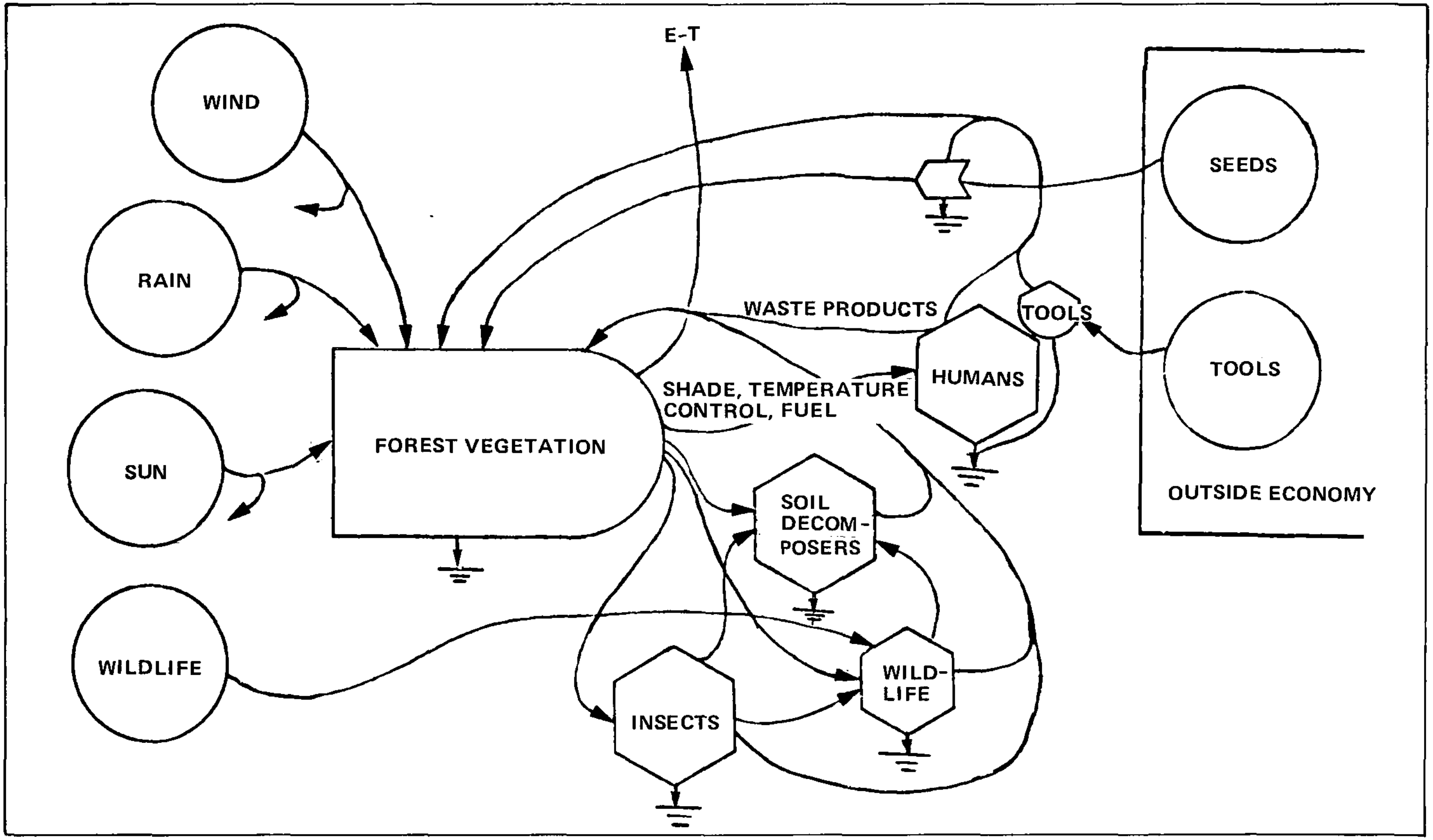

Figure 8. An energy model of the "urban forest" landscape.

This is an important ecological benefit since many ecologists have predicted that the vast destruction of wildlife habitat will be one of the major environmental issues during the next twenty years. It should be noted that some people might consider this characteristic a *disadvantage* due to the potential presence of "undesirable" snakes, rodents and insects.

CONCLUSIONS

The results of the analyses described in this paper include the somewhat surprising conclusion that the addition of trees and shrubs to a residential landscape consisting of only a lawn may actually increase indirect energy inputs associated with landscape maintenance. However, an energy analysis of alternate landscape designs has revealed that the installation of an appropriate "energy conservation" landscape can reduce the indirect energy inputs for maintenance. After an initial establishment period, the energy inputs of fertilizers, pesticides and water can be dramatically reduced by utilizing relatively simple water conservation techniques and by selecting native trees and shrubs which are appropriate to the site and are disease and drought resistant. Consequently an energy conserving landscape can not only reduce the electrical energy used in air conditioning a residence, but can also reduce the indirect energy inputs required in maintenance.

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