RESPONSES TO CLIMATE AND CULTURE

The Larger Scope of Housing: Infrastructure

Steven Van Dessel and Kristan Seymour
Rensselaer Polytechnic Institute

Abstract
Increased industrialization and spatial specialization has resulted in a mode of living that relies heavily on physical infrastructures and exploitation of remote resources. It becomes increasingly clear that such a model may not be sustainable for both environmental and economical reasons, especially for developing countries. Hence the search for alternate and more efficient models is to be promoted. In this paper, we present the notion that houses together with their immediate environment and the people that occupy the house can be designed as self-sufficient ecological units. We further indicated the technical feasibility of this proposition. In order to give physical meaning to this concept, we provided some quantitative data on material and energy flows for typical US residences.

Introduction
Many people throughout the world live under conditions of extreme poverty. Roughly 1.2 billion people continue to live below the poverty line of $ 1 per day [1]. These people experience hunger, are malnourished, lack access to safe drinking water, are poorly educated, and have no house to live in. As a consequence of poverty, human rights are lacking in many places of the world today. These include the right to a healthy lifestyle and proper nourishment, but also the right to adequate housing, as enshrined in the universal declaration of human rights. The past century has experienced a sharp increase in the number of homeless people or people living under inadequate housing conditions. Factors such as rapid population growth, shifting economic and cultural fabrics and related migration from rural to urban regions contribute significantly to this reality. It is estimated that half of the urban population, approximately 25 percent of the world population, lives in slums of some kind, one hundred million are utterly homeless, and between thirty and fifty percent of city dwellers lack access to basic drinking water and sanitation facilities. Increased occurrence and impact of natural and man-made disaster, including armed conflict, further aggravate current conditions [2].

The provision of shelter has traditionally been an important aspect of dealing with the housing problem. During recent years, however, the framework in which we think about housing has also expanded into many other territories. Security of tenure and the notion that housing issues cannot be separated from their socio-cultural and economic contexts are all considered critical. Many new territories have also been identified at the technological level. For example, total energy use as measure of economic and environmental performance, and the notion that systems are to be compared on a life cycle basis are considered critical in the understanding of the overall issue.

While infrastructures that provide water, food, and electricity and those that dispose our waste are critical parts of the total housing system, they are frequently not considered as part of the housing problem. It becomes increasingly clear that the global housing issues cannot be disconnected from the larger technological and ecological framework needed to support the activities that occur within the house. Our way of living today is intricately connected to remote infrastructures and resources. The food we eat, the phone calls we make, the trash we place on the curb, the electricity we consume, the roads we use to travel, the mail we receive, or the goods we acquire are provided to us increasingly to our convenience. Vast infrastructures constitute the backbone of our economies; they have brought us economic prosperity and have allowed us to increase our health conditions for more than a century.

This paper analyzes existing trends in the domestic American lifestyle, with the hope to encourage the general rethinking of infrastructure. The evidence suggests that infrastructure might begin to shift from a large scale, remote access process to a smaller scale, more independent and local process.

Physical Infrastructures

Increased industrialization and spatial specialization has widened the gap between environmental resources and the destination of consumer products. While this condition has evolved over centuries, it is only in the last decades that it has reached true global proportions. Such mode of living requires vast physical infrastructures, the footprint of which is steadily increasing as they form an indispensable link in the global material chain. Consequently, a steady increase of energy consumption occurs as the mean distance between goods and people continues to rise. The building of houses, and the establishment and maintenance of viable communities forms an important link within the global material and energy flows.

While current physical (and social) infrastructures in America appear normal, they are not in many other places of the world. It is estimated that over 1 billion people do not have access to an adequate supply of safe water and nearly 3 billion people lack a sanitary means of excreta disposal [3]. In many occasions, these communities may not have the financial means to build the vast infrastructures we are accustomed to. In addition, while the economic means to install infrastructures are considerable, the effort it takes to operate, maintain, and upgrade them are also staggering. For example, the American Society of Civil Engineers estimated that 1.3 trillion dollars are needed in the next 5 years for maintenance and repair of current infrastructure in the US alone [4]. Also, many water supply and sanitation facilities in third world economies are currently collapsing because resources for maintenance and operation are lacking [5]. Many environmental consequences further arise from current infrastructures. Not only do they require many resources for construction and maintenance, they often form painful intrusions in our landscapes. While vast infrastructures remain economically feasible for the majority of the population within our economy, they add significant financial burden to the provision of livable communities in third world economies. Also, within a global context, the environmental consequences of resource consumption and the building of infrastructures affect both industrialized and less industrialized regions of the world. Given this, it is essential that new models are being explored that are both economical and environmental benign.

Self Sufficient Housing?

As globalization continues to move forward, it is important to assess to what extend residential material flows and the consequently building of infrastructures can be reduced. As an extreme case, one could envision a scenario were no materials enter or leave the house. In such scenario, houses operate more independent of external infrastructures. Within this self-sufficient housing model, all of the physical necessities to exist are assumed to be resolved within the context of the house and its site. This implies that water, food, energy, and means to communicate are resolved within the building and that all waste streams are being resolved as well. In its most ideal form, such a house will allow people to live and communicate without the need to excessively stress the external environment. This type of housing infrastructure could further exist in both rural and urban settings and might accommodate a mode of living that does not deviate significantly from the practical routines and comforts we are currently accustomed to. Self-sufficient housing infrastructures might be attractive for numerous reasons. Economic benefits might result by cutting down on distribution; and by the opportunity to incrementally optimize individual systems without percolating financial consequences. Environmental benefits might result when energy needs are resolved on site or within the building, and when material inputs and outputs can be resolved and optimized in a sustainable way. By utilizing local resources, upstream and downstream consequences might also be avoided.

The notion of self-sufficiency is by no means new. In many of its historical aspects the house has been this node of existence providing the windows and doors through which we perceive and engage the world. The self-sufficiency model also continues to comprise the mode by which isolated communities around the globe exist. Small farms, rural and island communities, religious or other communities are often self-sufficient either by choice or necessity. Earlier forms of societal organization are also highly localized. While trade has a long history, early villages and cities derived many of their commodities such as food and water locally. Availability of adequate environmental resources was often the necessary condition for settlement. The motives that drive settlement have however shifted significantly since, resulting in mismatches between local material resources and basic physical needs. While notions of self-sufficiency are well established, self-sufficiency at the compact scale of the house is yet to be accomplished. Many indicators exist that suggest the technical feasibility of such self-sufficient housing proposal.

Context America: Residential Consumption Patterns

Many questions remain to be addressed in order to assess the economic and technical feasibility of self-sufficient housing infrastructures. It is essential however that we first understand the amount of resources that are currently needed to sustain the activities that occur within our houses. In the following sections we will describe energy and material flows for a typical US household. The objective here is to give physical meaning to the concept of self- sufficiency in a given context. The topics covered include, water, food, energy, solid waste, sewage, and construction.

Water:

The U.S. has generally seen large-scale centralized infrastructure for delivery and return as the best option when it comes to water, wastewater and storm water. The general feeling that water is both abundant and inexpensive has created a culture that consumes, per person, about 80-100 gallons of water a day [6]. A typical four-person household that gets its water from a public source uses approximately 350 gallons of water per day. Over 85 percent of U.S. citizens receive their domestic water from a public supply and that number continues to rise as the population becomes less rural [7]. Water used for household purposes includes such things as drinking, food preparation, bathing, washing clothes and dishes, flushing toilets, car washing, and watering of lawns and gardens (Table 1.A). Domestic use is separated into inside household uses (bathing, flushing toilets, laundry, cleaning, and cooking) and outside household uses (lawn and garden watering, car washing, and pools). Inside use tends to be consistent year round while outside use increases during specific seasons, usually summer, depending on the type of climate. In a study conducted by the U.S. Department of Housing and Urban Development, it was found that the largest percentage of indoor water use went to bathing and flushing while outside use varies greatly. Arid areas of the country can see over 60 percent of water consumption going to outside uses while more humid areas use a percentage near zero [8]. It's worth considering that the amount of potable (pure) water needed by the average American for cooking and drinking is 3 gallons per day [9].

Food:

A fundamental goal of modern societies has been to work towards a healthy population that has access to healthy food. In 1900, many U.S. households relied on regional food production. Low caloric intake and inadequate amounts of certain vitamins and minerals were the major nutritional problems [10]. Today, U.S. consumers enjoy an abundance of nutritious and affordable foods available year round. The U.S. food industry is a complex network of food processors, refiners, manufacturers, wholesalers, and retailers that transform agricultural and marine products into domestic goods. This system has created a network centered on pre-processed and packaged products intended to increase convenience and safety. The annual consumption of food products in the U.S is based on a per capita measurement, in other words, how much the average individual consumes during the year (Table 1.B). This annual consumption includes meals eaten in and away from the home. Today U.S. citizens dine outside the home for over 30 percent of their total consumption [11]. Specific product consumptions are also examined. Americans eat over 190 pounds of meat each year. Of that, red meat was the largest percentage at 111.0 pounds, poultry at 64.8 pounds and fish at 14.5 pounds [12]. Dairy products are more widely consumed then any other category at 580 pounds. Eggs and egg products play an important part in the U.S. diet. Annually, 238 eggs are consumed per capita directly as shell eggs or as ingredients in processed foods. Added fats and oils make up another major category with an annual per capita consumption of over 65 pounds [12]. The U.S. diet has increasingly embraced the consumption of fruits and vegetables. Total per capita consumption of fresh fruit averages just above 130 pounds while processed use is over 160 pounds. Total per capita consumption of Vegetables averages 416 pounds, of that; 185.6 pounds are fresh and 230.4 pounds processed [12]. Americans diets include a large quantity of flour and cereal product at 200 pounds per capita. A large percentage of this quantity comes from pre-packaged foods such as crackers, pretzels, corn chips, popcorn, and breakfast cereals [12]. The American population has become conspicuous consumers of added sugar, sweet tasting foods and beverages. Per capita consumption of a record 154 pounds continues to increase each year. Over three quarters of the sugar consumed enters the home through industrially produced goods and a fifth of that comes from carbonated soft drinks. As with many of the other categories, pre-packaged products are changing the consumption habits of Americans. Remaining categories that play a part in the American diet include tree nuts and peanuts at 8 pounds, coffee at just over 9 pounds, cocoa at 4 pounds and tea at just under a pound [12].

Energy:

The last two decades have seen a 33 percent increase in the total number of household in the United States, rising from 76.6 million to 101.5 million by 1997. There has also been a marked increase in the size of each housing unit [13]. Today the average individual housing unit uses 101 million Btu per year with 51 million Btu going to heating requirements. The majority of the remaining energy use falls into the categories of cooling, lighting and appliances. The last two decades have seen a decrease in the total energy use for space heating but there has been a 17 percent increase in energy demand for lighting and appliances [13]. Natural gas is the most frequently used heating fuel in the American home at 52 percent. Electricity, which is increasing in popularity, is currently used by 30 percent of housing units and 10 percent use fuel oil or kerosene for space heating [13]. Secondary heating systems, used to supplement the primary source, are incorporated in approximately 35 percent of U.S. housing units. Appliance ownership and use has been on a steady rise over the last two decades. Microwave and dishwasher use has had the largest percentage increase. Table 1.C provides direct and indirect fossil fuel consumption for the average US residence.

Solid Waste:

In 1999, the U.S. generated approximately 230 million tons of municipal solid waste (MSW), which equals about 2.1 Kg (4.6 pounds) per person, per day [14]. Between 55 and 65 percent of this amount is residential waste, the remainder being mainly commercial and institutional waste [15]. MSW in part consists of product packaging, grass clippings, furniture, clothing, bottles, cans, food scraps, paper, appliances, paint and batteries. (Table 1.D) The disposal of these items generally takes place at landfill or incineration facilities. Each of these methods evokes concern for ecologic and land use issues and these fears have led to increased source reduction, recycling and composting practices. Unfortunate, land filling and incineration still remain the prevailing methods for MSW disposal in the United States (73% and 14% respectively). Current estimates indicate that only a few percentage of MSW is reused or recycled [14].

Sewage:

Until recently, thousands of American cities dumped raw sewage directly into surrounding rivers, lakes and bays. Improved wastewater management standards that came about from stricter Federal and State regulations has allowed for safer waterways. The treated bio-solids from wastewater treatment are most often recycled, incinerated or buried in a landfill. The daily flow of sewage in the average U.S. household differs from the supply flow, considering water used for irrigation, car washing or loss to evaporation generally don't enter a waste system. Of the potable water that does enter the system; a majority is employed for flushing or washing. For the average U.S. citizen this totals nearly 60 gallons per day (Table 1.E) [9]. There are considerable consequences to this conventional approach to waste management. Alternative systems create an opportunity from the waste, treating it as a resource and not a pollutant.

Enclosure (building materials & maintenance)

Waste products from housing construction produce 15 to 30 percent of the total waste deposited in landfills annually and many contain toxic constituents. These wastes include rubble, wood and wood products, plaster, plastics, metal, insulation adhesives and paint [16]. The average size of a new U.S. residence sits on a lot that is .33

Table 1 Resource consumption patterns for the US house [from references 15–29].

A. WATER	Gallons per capita per day	Gallons per capita per year	Gallons per house per year	Kilogram per house per year (=liters)
Bathing	20	7300	29200	110534
Toilet flushing	24	8760	35040	132641
Laundry	8.5	3102	12410	46977
Dishwasher	4	1460	5840	22107
Drinking & Cooking	3	1095	4380	16580
Garbage Disposal	1	365	1460	5527
Car Washing	2.5	912.5	3650	13817
Lawn & Pool	25	9125	36500	138167
Total	88	32120	128480	486349

B. FOOD	Pounds per capita per day	Pounds per capita per year	Pounds per household per year	Kilogram per household per year
Meat	0.521	190	760	345
Dairy	1.589	580	2320	1052
Eggs	0.082	30	120	54
fats & oils	0.178	65	260	118
Fruits	0.795	290	1160	526
Vegetables	1.140	416	1664	755
flour & cereal	0.548	200	800	363
Sugars	0.422	154	616	279
Nuts	0.022	8	32	15
Coffee	0.025	9	36	16
Cocoa	0.011	4	16	7
Tea	0.003	1	4	2
Total	5.334	1947	7788	3533

C. FOSSIL FUEL	Kilogram per house per year
Natural Gas	2312
Fuel Oil	2524
LPG	2.57
Kerosene	377
Indirect Fuels (to generate electricity)	
Coal	3743
Gas	699
Petroleum	101
Total	9758

D. SOLID WASTE	% total	Pounds per capita per day (total)	Pounds per capita per year (total)	% disposed at home	Pounds per capita per year (at home)	Pounds per house per year	Kilogram per house per year
Paper	37.4	1.7204	628	0.6	377	1507	684
yard waste	12	0.552	201	0.6	121	484	219
food waste	11.2	0.5152	188	0.6	113	451	205
Plastic	10.7	0.4922	180	0.6	108	431	196
Metal	7.8	0.3588	131	0.6	79	314	143
rubber, textiles,...	6.7	0.3082	112	0.6	67	270	122
Glass	5.5	0.253	92	0.6	55	222	101
Wood	5.5	0.253	92	0.6	55	222	101
Other	3.2	0.1472	54	0.6	32	129	58
Total		4.6	1679		1007	4030	1828

E. SEWAGE	Gallons per capita per day	Gallons per capita per year	Gallons per house per year	Kilogram per house per year (~liters)
Total	60	21900	87600	331602

F. STRUCTURE	Pounds per house (50 years)	Kilogram per house (50 years)	Kilogram per house (per year)
Ceramic	1671	758	15
PVC	1834	832	17
Particle board	2284	1036	21
Steel	5207	2362	47
asphalt shingles	6193	2809	56
Oriented strand board	14844	6733	135
Gypsum	27659	12546	251
Wood	32917	14931	299
Gravel	131550	59670	1193
Concrete	379173	171990	3440
Total	605004	274425	5489

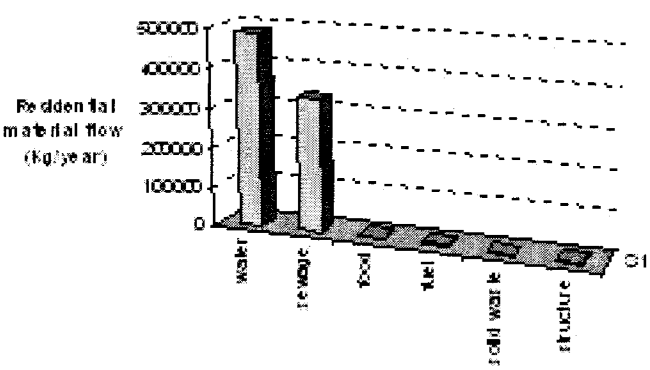

Fig. 3 Average yearly flow of material for US houses

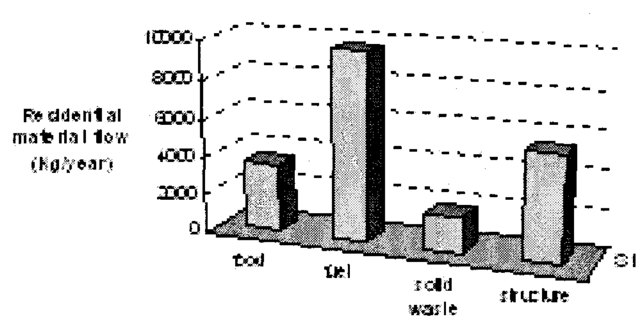

Fig. 4. Average yearly flows of food, fossil fuel, solid waste, and structure for US houses

many economical comparable countries manage to operate on much less residential water per capita, using only 25% of the water consumed in the US house.

Sewage:

Sewage represents a significant fraction of the residential material flow, being closely related to water use. Many means to dispose sewage on-site are currently available. These include for example conventional septic tanks for primary treatment combined with drain fields for secondary treatment. Other means involve the construction of wetlands, and greenhouse ecosystems such as the "living machines". While sewage is considered disposable, it has in fact value. For example, studies have indicated that nutrients present in municipal sewage can be successfully recycled for crop growth using hydroponics, the growing of plants without soil [20]. In other words, most sewage can supply almost all nitrogen and most of the

Table 2 Square meters of horizontal surface needed to capture enough water to accommodate specific task.

RAINFALL	Annual rainfall in inches	60	50	40	30	20	10
	Annual rainfall in meters	1.524	1.27	1.016	0.762	0.508	0.254
WATER USES	Cubic meter per year per family	Square meters of horizontal surface needed to capture enough water to accommodate specific task					
Bathing	111 m3	74	87	109	145	218	435
Toilet flushing	133 m3	87	104	131	174	261	522
Laundry	47 m3	31	37	46	62	93	185
Lawn & Pool	138 m3	91	109	136	181	272	544
Car Washing	14 m3	9	11	13	18	27	54
Drinking & Cooking	17 m3	11	13	16	22	33	65
Garbage Disposal	6 m3	4	4	5	7	11	22
Dishwasher	22 m3	14	17	22	29	44	87
Totals		319	383	479	638	957	1915

phosphorus and other micronutrients required by many crops [21]. Since crops require large amounts of nutrients dissolved in water, and since municipal wastewater is a good source of such material, it forms a logical source of such materials [22]. Another attractive feature of this approach is that food is being produced while the potential pollution of wastewater is reduced.

Food:

Considering the self-sufficient housing model, it is of interest to know whether or not food production can be collapsed to the scale of a typical (urban) house. Investigating self-sufficient habitats designed for extreme or small environments may proof beneficial in this context. Concepts in space exploration have triggered both theoretical and experimental work in this area. In anticipation of long-term space missions, both the Russian and US space programs have included experimentation with closed loop systems. The Russian Bios-3 experiment for example supported a crew of three people within a 315 m3 enclosure for 4 months. A 65 m2 area for crop growth was included within this enclosure that provided a significant part of the food supply during these experiments [23,24]. Experiments like this demonstrate that closed loop systems similar in scale to a small house may well be feasible. In the same context but larger in scale, the biosphere 2 experiment in Arizona is likely the most extensive technology based closed habitat to date. With a total volume of 180, 000 m3 and a floor area of 1.27 ha this complex was able to sustain a crew of eight people and multiple ecosystems for a period of 2 years [25, 26]. Many issues have been addressed that might be useful when formulating self-sufficient housing proposals. However many of the self-sufficiency objectives described above have not been addressed. Most notably, the energy needed to operate the biosphere 2 complex was not resolved without major external input [27]. In addition, many aspects of the complex depend so much on elaborate technical installations that the question can be raised whether or not such approaches are scalable to the size of a typical house or are economical feasible for a wide population. However, such experiments demonstrate the feasibility of certain aspects of self-sufficiency.

Context:

The applicability of the self-sufficient housing concept to different settings may not always be obvious. For example, within a rural community some aspects of self-sufficiency, such as provision of food, are easier to deal with since more land is available for agriculture. Considering this, one naturally assumes that such constraints result in spatial specialization. Urban farmers, people who produce food within the city confines, have successfully dealt with agricultural spatial challenges. It is estimated that there are currently some 200 million urban farmers in the world, supplying food to 700 million people. Also urban farming provides for 30 percent of vegetable consumption in Kathmandu, 50 percent in Karachi and 85 percent in Shanghai. A long history of urban farming further exist in Asia were some 50 percent of urban households currently farm [28]. In light of this and considering increased urbanization worldwide, the UN food and agricultural organization has recently started to promote urban farming practices in developing countries [29]. Experiments related to the various space programs further indicate that farming methods can be developed that are less space intensive. Hence, a more significant form of urban farming may well be feasible in the future.

Concluding remarks

The search for affordable housing has traditionally focused on the provision of shelter. While this remains an important aspect of the global housing issue, it is clear that many other issues need to be considered as well. While the infrastructures that provide water, food, and electricity and those that dispose our waste are critical parts of the total housing system, they are yet to be included in the housing equation. Increased urbanization and spatial specialization has resulted in a mode of living that relies heavily on physical infrastructures and exploitation of remote resources. It becomes increasingly clear that such a model may not be sustainable for both environmental and economical reasons, especially for developing countries. Hence the search for alternate and more efficient models is to be promoted.

In this paper, we presented the notion that houses together with their immediate environment and the people that occupy the house can be designed as self-sufficient ecological units. We further indicated the technical feasibility of this proposition. In order to give physical meaning to this concept, we provided some quantitative data on material and energy flows for typical US residences. It is obvious that representing current US context as a global standard is quite irresponsible. However, taking such a "worst case" scenario as baseline may be beneficial if we want to accomplish robust self-sufficient housing proposals. While site resources could match residential needs, significant design challenges lie ahead to accomplish self-sufficient houses. It is clear that adopting a self-sufficiency standard for houses will make the housing equation more complex. However it may reflect or address the complexity of the housing issue more truthfully.

Acknowledgements

The contribution of Kristan C. Seymour in gathering and presenting the resource consumption patterns for US houses, and of Amy Farina in strengthening general important aspects of this manuscript, is acknowledged.

References

1 Chen Shaohua and Ravallion Martin, How Did the World's Poorest Fare in the 1990s? Policy Research Working Paper # 2409, Development Research Group, World Bank, 2000
2 United Nations World Urbanization Prospects, the 1999 revision, United Nations, (http://www.undp.org/popin/wdtrends/urbanization.pdf)
3 Sustainability and optimization of water supply and sanitation services, Operation & Maintenance working group (OMWG) of the World Health Organization, (http://www.who.int/water_sanitation_health/wss/sustoptim.html)
4 Civil Engineers Give Nation's Infrastructure a "D+", 2001 Report Card for America's Infrastructure, American Society of Civil Engineers,(http://www.asce.org/news/pr030801_reportcard.cfm)
5 Global Water Supply and Sanitation Assessment 2000 Report, WHO/UNICEF, 2000
6 "How Much Drinking Water Do We Use in Our Homes?", Environmental Protection Agency, http://www.epa.gov/OGWDW/wot/howmuch.html
7 "Trends in Domestic Water Use", U.S. Geological Survey, http://wwwga.usgs.gov/edu/graphicshtml/dopsss.html
8 "National Handbook of Recommended Methods for Water Data Acquisition --Chapter 11 - Water Use", U.S. Geological Survey, http://water.usgs.gov/pubs/chapter11/
9 Benjamin Stein and John S. Reynolds, "Mechanical and Electrical Equipment for Buildings", Ninth Edition, 1999, John Wiley and Sons, Inc. New York, pp. 531-766
10 "A healthy, well-nourished population", Economic Research Service of the U.S. Department of Agriculture, http://www.ers.usda.gov/Emphases/Healthy/index.htm

11 "What We Work For Now: Changing Household Consumption Patterns in the 20th Century", Redefining Progress, http://www.rprogress.org/programs/commonassets/whatwework.html

12 "Major Foods Per Capita Consumption", Economic Research Service of the U.S. Department of Agriculture, http://www.ers.usda.gov/briefing/consumption/

13 "Residential Energy Consumption Survey", Energy Information Administration at the Department of Energy, http://www.eia.doe.gov/emeu/recs/contents.html

14 "Municipal Solid Waste", Environmental Protection Agency, http://www.epa.gov/epaoswer/non-hw/muncpl/facts.htm

15 "Produce Less Waste", Environmental Protection Agency, [24] "Municipal solid waste in the United States, 2000 Facts and figures", Office of solid waste and emergency response, US Environmental Protection Agency, 2000, http://www.epa.gov/epaoswer/non-hw/muncpl/report-00/report-00.pdf

16 "Pollution Prevention/Environmental Impact Reduction Checklist For Building/Housing Construction", Environmental Protection Agency, http://es.epa.gov/oeca/ofa/pollprev/build.html

17 "American Housing Survey for the United States: 1999", U.S. Census Bureau, American Housing Survey Branch, http://www.census.gov/hhes/www/housing/ahs/ahs99/tab1a3.html

18 "Housing Facts and Figures: Characteristics of New Single Family Homes", National Association of Home Builders Economics Department, http://www.census.gov/hhes/www/housing/ahs/ahs99/tab1a3.html

19 Blanchard Steven and Reppe Peter "Life Cycle Analysis of a Residential Home in Michigan", Center for Sustainable Systems, University of Michigan, September 1998 http://css.snre.umich.edu/css_doc/CSS98-05.pdf

20 Vaillant N., Monnet F., Vernay P., Sallanon H., Coudret A., Hitmi A., "Urban wastewater treatment by a nutrient film technique system with a valuable commercial plant species", Environmental Science & Technology, Volume 36, Issue 9, May 1, 2002, Pages 2101-2106

21 Boyden B. H. and Rababah A.A., "Recycling nutrients from municipal wastewater", Desalination, Volume 106, Issues 1-3, August 1996, Pages 241-246

22 Sias, D.R., and Nevin, T.A., "Experimental hydroponic gardening with municipal waste-water", Bulletin of Environmental Contamination and Toxicology, Volume 10, Issue 5, November 1973, Pages 272-278

23 Terskov I.A., Gitelson, J.I., Kovrov, B.G., et al. 1979. Closed System: Man Higher Plans (Four Month Experiment) translation of Nauka Press, Siberian Branch, Novocibirsk, 1979, NASA-TM-76452.

24 Nelson M., Dempster, W.F., 1996. Living in space: results from Biosphere 2's initial closure, an early testbed for closed ecological systems on Mars, AAS 95-488. In: Stoker, C.R., Emmart, C. (Eds.), Strategies for Mars: A Guide to Human Exploration, vol. 86, Science and Technology Series, American Astronautical Society, San Diego, CA, pp. 373¯390

25 Marino Bruno D. V., Tilak Ram Mahato, John W. Druitt, Linda Leigh, Guanghui Lin, Robert M. Russell and Francesco N. Tubiello The agricultural biome of Biosphere 2:; Structure, composition and function, Ecological Engineering, Volume 13, 1999, Pages 199-234

26 William F. Dempster, Biosphere 2 engineering design, Ecological Engineering, Volume 13, Issues 1-4, June 1999, Pages 31-42

27 John Allen and Mark Nelson Overview and Design Biospherics and Biosphere 2, mission one (1991¯1993), Ecological Engineering, Volume 13, Issues 1-4, June 1999, Pages 15-29

28 Feeding the Cities, The role of Urban Agriculture, World Food Summit, Food For All, Rome 13-17 November 1996

29 Urban Agriculture: An Axymoron?, The State of Food and Agriculture 1996, Food and Agriculture Organization of the United Nations, Roma, 1996