BUILDING ENERGY CONSUMPTION AND THE ENVIRONMENT: WHAT PAST, PRESENT, AND FUTURE COMMERCIAL BUILDINGS ENERGY CONSUMPTION SURVEYS CAN TELL US ABOUT CHLOROFLUOROCARBONS

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One of the serious energy-related environmental issues that is the focus of much scientific research and concern to decision makers in both the public and private sectors, is the effect of the use of chlorofluorocarbons (CFCs). This paper uses data from the 1986 Commercial Buildings Energy Consumption Survey (CBECS) to quantify the types and amounts of CFCs used in the commercial building population in the United States. It describes the CFC-related information collected on the 1989 CBECS and identifies possible other areas of data collection for future cycles of the survey.

[1] *The opinions and conclusions expressed herein are solely those of the authors and should not be construed as representing the opinions or policy of any agency of the United States Government.*

INTRODUCTION

CFCs and halons are used extensively throughout the commercial, manufacturing, residential and transportation sectors of the economy for both energy and non-energy uses. These families of organic compounds have been ideal for many different uses because they are non-toxic, safe, nonflammable and long-lived. Unfortunately, evidence accumulated over the past 15 years indicates that CFCs have caused measurable deterioration of the earth's ozone layer, which plays a significant role in attenuating solar ultraviolet radiation. Increased levels of ultraviolet radiation are associated with a large number of undesirable effects, including cataracts, changes in the human immune system and increased levels of skin cancers. Over the past few years, this subject area has received renewed attention as the result of observations in the mid-1980's of "gaps" in the ozone layer in the vicinity of the South Pole. As a result of this attention, the Montreal CFC protocols were concluded in September 1987 which require a freeze, then phased production curtailments of CFCs. By 1998, production of CFC-11, CFC-12, CFC-113, CFC-114, and CFC-115, as well as three halons (used primarily in fire extinguishers) is to be reduced to 50% of the 1986 levels. Related substances known as hydrochlorofluorocarbons (HCFCs) have also come under scrutiny. The attachment of a hydrogen atom to the CFC molecule weakens its molecular bonds and allows more rapid dissipation, thus lowering the Ozone Depleting Potential (ODP). For example HCFC-22, the most widely used HCFC, has an ODP of .05 compared to an ODP of 0.9 for CFC-12 and 1.0 for CFC-11. Even so, some atmospheric scientists and environmental activists have been calling for a complete ban on the production of all CFCs on an accelerated time scale and a broadening of the list of regulated/banned substances to include the HCFCs including HCFC-22.

In addition to depleting atmospheric ozone, the CFCs contribute to the global warming trend. Chlorofluorocarbons are considered greenhouse gases and the same gases that are predicted to modify ozone are also predicted to produce climate warming. Thus, control of CFCs and halons to prevent stratospheric ozone depletion will also help mitigate global climate change.

As shown in Figure 1, the main energy-related uses in the U.S. of the CFCs covered by the Montreal Protocol are for foam products, mobile air conditioning (transportation), and refrigeration (including building air-conditioning). Chlorofluorocarbons provide most of the best refrigerant fluids available, as well as the foaming agents in low-density insulating materials that have greatly improved the energy efficiency of both buildings and appliances. In addition, others are used as solvents and cleaners that have been described as almost indispensable in the production of energy-conserving electronics.

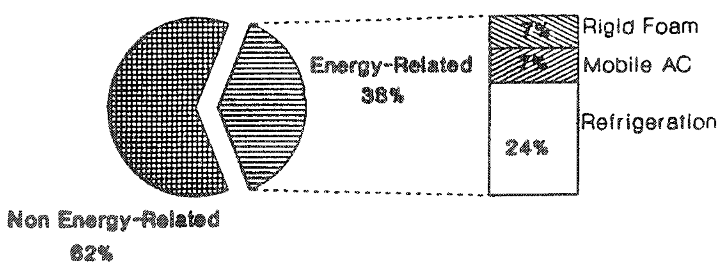
The commercial sector, as the fastest-growing energy-consuming sector of our economy, is a major user of CFCs. During the 1990s, the requirements of meeting the energy needs of commercial buildings while minimizing the environmental impacts will provide policymakers in the public and private sectors alike with a difficult challenge. To ameliorate these problems, analysts will need reliable data on commercial applications of CFCs and the potential effects of switching to other substances, and the potential for recycling and recapturing CFCs in commercial buildings. The Commercial Buildings Energy Consumption Survey (CBECS), which is conducted by the U.S. Department of Energy (DOE), will be an important source of information for DOE policymakers on the contribution to ozone depletion made by the commercial building sector. As the Federal agency responsible for promoting energy supply and end-use options for the future, DOE will play a major role in developing and implementing the U.S.'s energy response to all climate change issues.

This paper will use data available from the 1986 CBECS to describe energy-related CFC usage in the commercial buildings population, and wherever possible, to provide data on the quantities of CFCs involved in those uses. The analyses will deal with CFC-using equipment (both HVAC and non-HVAC), CFC-containing insulation, and equipment vintage. The latter topic is included because age turnover rates of existing equipment stock have implications for how to handle CFCs in existing equipment and how to move away from CFCs in the near future.

THE CBECS

The CBECS, formerly called the Nonresidential Buildings Energy Consumption Survey (NBECS), is conducted triennially by the Energy Information Administration (EIA), the independent statistical and analytical agency within DOE.

The purpose of the survey is to provide national and Census region-level estimates of energy consumption and expenditures in commercial buildings, and of building characteristics related to energy consumption patterns. The definition of a "building" is rather broad. A building is defined as a structure totally enclosed by walls extending from the foundation to the roof and intended for human



Source: Statt, T.G. 1988. "Use of Chlorofluorocarbons in refrigeration, insulation and mobile air conditioning in the USA." *International Journal of Refrigeration* 11(7):225.

Figure 1. 1985 U.S. Production of Ozone-Depleting Substances (1.54 billion lbs.)

occupancy. All commercial buildings over 1,000 square feet are included in the survey population. The definition of "commercial" is also broad and includes any building with more than 50 percent of its floorspace used for commercial activities. Commercial buildings include, but are not limited to, stores, offices, schools, churches, gymnasiums, libraries, museums, hospitals, clinics, warehouses, and jails. Excluded are buildings in which more than 50 percent of the floorspace is used for industrial, agricultural, or residential purposes.

The CBECS is the only publicly available survey of the current U.S. building stock that is statistically representative of the building population. Previous surveys have been conducted in 1979, 1983, and 1986. Data for the 1989 CBECS are currently being prepared for publication. At a minimum, each cycle of the CBECS has produced both national and Census region estimates of the number, square footage, energy consumption, and energy expenditures for the population of commercial buildings and for subpopulations defined by the following building-specific characteristics: use, location, energy sources, energy end uses, and conservation features such as roof and wall insulation and heating and cooling equipment and practices. The questions about the heating and cooling equipment specifically address chillers, individual room air conditioners, packaged units, and other types of heating and cooling equipment.

WHAT THE 1986 CBECS CAN TELL US ABOUT CFC USAGE IN BUILDINGS

CFC-Using Cooling (HVAC) Equipment

The 1986 CBECS provides a different perspective than generally referenced literature on CFC usage in commercial buildings cooling equipment. CBECS, because of its design, provides building-level information on the presence of applicable equipment, rather than equipment-based data on production, sales or installations.

An important example of the uncertainty and disparity caused by these different measures occurs for the population of commercial chillers, which are widely used for space conditioning. Selected sources illustrate the range of estimates:

- EIA, 1988 347,000 buildings (10,000 square feet or larger) with central cooling (chillers) in 1986.
- ORNL, 1989 50,000 "chillers in use."
- RAND, 1986 30,000 "domestically installed central chillers between 1976 and 1984."
- EPA, 1989 approximately 175,000 "domestically consumed chillers between 1955 and 1985."

The inconsistencies in these estimates are mostly the result of differing sources, definitions, assumptions, and methodologies used in collecting and analyzing the data. The RAND, ORNL and EPA numbers are the result of various analyses of chiller production numbers, mostly taken from the Bureau of Census' industrial reports and various industry sources.

In contrast, the 1986 CBECS gathered the chiller information at the building site. However, the 1986 CBECS asked if the building had "central cooling (for example, chillers)" as opposed to asking specifically about the presence of central chillers. Some of the 347,000 buildings with chillers on the 1986 survey could actually have had packaged units or another type of system that delivers centrally-conditioned air rather than custom-designed systems based on central chillers. The 1989 CBECS used a tighter definition and approach and should provide a more accurate and lower estimate of the number of buildings with chillers.

However, even the improved estimates from the 1989 survey will not provide a complete national estimate of chiller penetration. Neither the 1986 or 1989 survey asked for data on the number or types of chillers present, information that would provide a more complete description of the chiller population in commercial buildings. Furthermore, chillers installed in buildings that are predominately industrial, agricultural, or residential are outside the scope of the CBECS and also would not be counted.

Using the CBECS data on cooling equipment, a rough estimate of the number of tons of air-conditioning and the number of pounds of CFC-11, CFC-12 and HCFC-22 in use in commercial buildings in 1986 can be calculated (Table 1).

Three parameters were used to calculate these estimates: (1) individual building averages for square foot per ton of cooling capacity (TRW 1982 and

Table 1. Distribution of Air-Conditioning Tonnage and Refrigerant Type by Principal Building Activity and Year Building was Constructed

Table 1a. Cooling Equipment Assumed to Be Using CFC 11 or 12

Building Characteristic	Number of Buildings (thousand)	Estimated Square Feet/Ton	Cooled Area (Million Square Feet)	Tons of Air-Conditioning (MM)		Pounds of Refrigerant (MM pounds)
				Centrifugal	Reciprocating	
All Buildings	1,111	NA	9,333	22,445	6,555	125,147
Principal Activity						
Assembly	196	330	1,574	2,765	1,870	20,488
Education	53	260	1,331	4,470	372	20,733
Food Sales/Service	93	315	362	631	486	4,998
Health Care	21	260	566	1,925	89	8,416
Lodging	29	300	410	1,136	158	5,584
Mercantile/Service	314	325	1358	2,449	1,524	17,289
Office	282	320	2,864	6,958	1,388	35,494
Warehouse	58	350	348	964	129	4,681
Other	34	320	305	782	203	4,345
Vacant	32	350	214	364	336	3,120
Year Constructed						
1960 or Before	465	NA	3,464	5,378	5,537	48,051
1961 to 1979	472	NA	4,522	13,027	1,018	60,032
1980 to 1986	174	NA	1,347	4,040	1	17,064

Table 1b. Cooling Equipment Assumed to Be Using HCFC-22

Building Characteristic	Number of Buildings (thousand)	Estimated Sq. Ft. per Ton	Cooled Area (MM sq. ft)	Tons of Air-Conditioning (Millions)				Pounds of Refrigerant (MM pounds)
				Packaged Units	Individual A/C Units	Reciprocating Units	Heat Pumps	
All Buildings	2,122	NA	17,278	28,418	14,757	5,890	6,853	194,723
Principal Activity								
Assembly	265	330	2,032	2,430	1,909	1,055	716	21,226
Education	123	260	1,726	3,582	2,292	303	443	23,111
Food Sales/Service	212	315	929	1,687	551	448	238	10,148
Health Care	37	260	1,063	2,559	1,253	52	221	14,289
Lodging	85	300	1,190	782	2,303	298	569	13,781
Mercantile/Service	661	325	4,707	8,662	2,977	1,196	1,584	50,253
Office	433	320	3,962	5,925	2,080	1,957	2,317	42,643
Warehouse	172	350	880	1,610	652	211	453	10,213
Other	69	320	411	594	364	223	174	4,704
Vacant	65	350	378	586	378	149	Q	4,355
Year Constructed								
1960 or Before	826	NA	4,884	6,863	7,740	--	1,278	55,586
1961 to 1979	900	NA	7,978	13,256	5,643	3,717	3,139	89,297
1980 to 1986	396	NA	4,417	8,299	1,374	2,174	2,436	49,840

Q = Withheld because relative standard error is greater than or equal to 50 percent.
-- = Assumed to be zero.
Source: Energy Information Administration, Office of Energy Markets and End Use, Energy End Use Division, Form EIA-871A, "Building Questionnaire," of the 1986 Nonresidential Buildings Energy Consumption Survey.

RAND 1986); (2) working fluid characteristics as a function of equipment type (ORNL 1989); and (3) refrigerant charge per ton of cooling capacity (Little 1989).

A four-step estimation process was followed to derive the estimates: (1) the most frequently-used working fluids were assigned to the CBECS equipment types (central systems, packaged cooling systems, individual room air conditioners, and heat pumps). CFC 11 and 12 are usually found in chillers used in central air conditioning systems in buildings over 10,000 square feet [except for the very large central systems with 5,000 to 10,000 ton chillers which use a mixture of CFC-500 and HCFC-22 (ORNL 1989)]. HCFC-22 is used as the working fluid in packaged cooling systems, individual or room air-conditioners; in very large central systems (as mentioned above) and in small central systems, those with capacity ratings at 25 tons of cooling or less; (2) using industry averages for the square foot of floor area per ton of air-conditioning capacity in different building types, size limits for the working fluid were assigned. For example, it was assumed that equipment in buildings with 10,000 or fewer square feet of mechanically cooled space use HCFC-22 as the cooling medium; (3) a typical refrigerant charge per ton of cooling capacity was assigned to the working fluid; (4) CBECS data on square footage of air conditioned space were converted to tons of cooling capacity, and by extension, to estimates of total required refrigerant charge.

Using these factors and assumptions, there were an estimated 56 million tons of cooling capacity in commercial buildings in 1986 using HCFC-22. Using a typical refrigerant charge of 3.5 (3 to 4) pounds per ton of cooling capacity (Little 1989), would mean there were about 195 million pounds of HCFC-22 used in commercial buildings in 1986.

To calculate the amount of CFC 11 and 12 in commercial buildings, the same basic four step estimation procedure was followed except that a refrigerant charge of 4.5 (3 to 6) pounds per ton of cooling capacity (Little 1989) was used for CFC 11 and 12. This procedure produces an estimate of 9 billion square feet of floorspace in buildings over 10,000 square feet mechanically cooled with chillers. These commercial buildings contain approximately 29 million tons of cooling capacity using CFC 11 or 12 and 125 million pounds of CFC-11 and 12. In a separate, production-based study, EIA estimated that there were 97 million pounds of coolant in use for commercial air conditioning (EIA 1989). Given the difficulties in assumptions and methods used to derive these estimates, and the confusion in the 1986 CBECS between central cooling with packaged units and central chillers, these two estimates are in reasonable accord.

Information of this type is important to trade associations, public policymakers and public interest groups charged with implementing CFC reduction strategies. It indicates the number of buildings that would be affected, the number of tons of air-conditioning involved, and the quantity of CFC by building type. It provides policymakers not with just the gross national amount of CFCs (as provided by production statistics) but with information to design recycling, recapturing, incentive and retrofit programs tailored to meet the differing needs of the building owners and utilities that may be required to implement CFC reduction programs. It also provides rough estimates of the vintage of the equipment in buildings: buildings constructed in the 1960 and 70's are candidates for equipment turnover while those buildings constructed in the 1980s should contain equipment with a useful life well into the next century.

Commercial Refrigeration

Very little information about the stock of commercial cold storage refrigeration equipment exists. Cold storage refrigeration equipment used in the storage and distribution of meat, produce, dairy products, and other types of perishable goods are concentrated mainly in buildings such as refrigerated warehouses, food sales (e.g., supermarkets), and food service (e.g., restaurants). Schools, hospitals, laboratories and retail activities also use CFCs but in less significant amounts. Thus, rough estimates of cold storage refrigeration equipment containing CFCs can be obtained by analyzing the principal building activity, square footage, and measure of size information in the 1986 CBECS.

Of the CBECS building types, the most significant consumers of the CFCs associated with refrigeration equipment (principally, CFC 12 and CFC 502) are refrigerated warehouses. The 1986 CBECS estimates that there were 25,000 refrigeration units in the U.S containing 474 million square feet. The only other national level source of information on the capital stock of cold storage warehouses is the Biannual Survey of the Capacity of Warehouses in the U.S. conducted by the U.S. Department of Agriculture (USDA). The USDA survey estimates that in 1985 there were 3,198 refrigerated warehouses containing 1.7 million cubic feet (USDA 1986), or [by dividing this figure by 22.7, the average height of a refrigerated warehouse (EPA 1989)], 74.8 million square feet.

However, the coverage of the USDA survey does not include warehouses operated by wholesale distributors, grocery chains, or other businesses that store food products less than 30 days. The CBECS definition includes all buildings where 50 percent of the floorspace is artificially cooled to 50 degrees Fahrenheit or less, not just the subset targeted by USDA.

The 1986 CBECS did not gather information about the type of refrigeration equipment in refrigerated warehouses: only information on the heating and cooling equipment were gathered. Without knowing specifics on the types of refrigeration equipment, it is not possible to derive an estimate of CFC usage in refrigerated warehouses. In addition, there are widely varying estimates of the CFC charge required per ton of capacity (EPA 1989). If such estimates are deemed important, questions may be added to future rounds of the survey.

Insulation Blowing Agents

Every cycle of CBECS has gathered information on the presence of roof and wall insulation in the sampled building; however because of the respondents' inability to provide the information, data are not gathered on the type and thickness of the insulation used. Previously unpublished CBECS data used to develop an estimate of the area of roof and ceiling square footage in commercial buildings containing insulation are given in Table 2.

CFCs were not used in foam insulation until the early 1960s (RAND 1986). By 1986, virtually all insulation being installed in commercial buildings contained CFCs (EIA 1989). Most of the roof and wall insulation in commercial buildings appears in the most recently constructed buildings and tends to be installed at the time of construction. Not surprisingly, only a very small fraction of the wall space had insulation added after construction. Most post-construction installation occurred from 1980 to 1986 and can be assumed to contain CFCs.

CBECS data on the presence of roof and wall insulation, building floorspace, and number of floors were used to derive estimates of insulated roof and wall area. The estimate for roof or ceiling area was derived assuming equal-area floors, so that the roof or ceiling area could be calculated by dividing the total building square footage by the number of floors in the building. If the building reported roof or ceiling insulation, the entire area was assumed to be insulated. The estimate for wall area was calculated assuming equal-area, square, 12-foot high floors, which, if insulated, contained insulation in all of their non-glass area. Based on these assumptions, at least 14.7 percent (1,094 billion square feet) of the wall area and an equal percentage of the roof or ceiling area in commercial buildings can be assumed to contain CFCs.

The presence of CFCs in insulation board is not really a vital "energy issue." Researchers have determined that there is a minimal energy consumption penalty with the substitution of new types of non-CFC insulation board (ORNL 1989). And, because CFCs do not constitute a health hazard like asbestos, it is not necessary to remove existing insulation from buildings. This information is of most use to climate modelers and others trying to project CFC emissions from the existing stock that will be released to the atmosphere after the production of CFC-11 and 12 have been banned.

WHAT THE 1989 CBECS CAN TELL US

In response to DOE's interest in the impacts of the Montreal Protocol, EIA made changes to the 1989 CBECS that would enhance the analytic ability of the CBECS to evaluate the impact of CFC curbs. The timing of the 1989 CBECS, (at the start of the movement to curb CFCs) and its status as the only national survey of the existing U.S. building stock,

Table 2. Roof or Ceiling and Wall Insulation by Year Building was Constructed

Year Constructed	Wall Insulation: Thousand buildings	Wall Insulation: Million square feet	Wall Insulation: Wall area[a] (million sq. ft.)	Roof or Ceiling Insulation: Thousand buildings	Roof or Ceiling Insulation: Million square feet	Roof or Ceiling Insulation: Floor area[b] (million sq. ft.)
			Installed at Time of Construction			
All Buildings	1,548	24,078	7,480	1,930	30,950	19,116
1900 or before	19	266	116	23	370	123
1901 to 1920	27	524	183	35	869	358
1921 to 1945	85	1,626	533	119	2,161	962
1946 to 1960	210	2,495	863	306	3,872	2,605
1961 to 1970	299	4,687	1,485	406	6,490	4,184
1971 to 1979	438	7,029	2,088	517	8,571	5,464
1980 to 1986	469	7,451	2,212	524	8,619	5,421
			Added Since Construction--Before 1980			
All Buildings	155	1,817	777	309	3,419	2,017
1900 or before	17	276	134	40	604	211
1901 to 1920	21	402	148	38	683	337
1921 to 1945	49	500	216	99	976	600
1946 to 1960	34	332	144	69	634	522
1961 to 1970	22	173	83	35	286	180
1971 to 1979	12	110	46	27	212	142
1980 to 1986	2	25	7	2	25	25
			Added Since Construction--1980 to 1986			
All Buildings	306	3,338	1,381	518	7,958	4,539
1900 or before	30	334	186	41	473	140
1901 to 1920	28	200	123	45	436	213
1921 to 1945	71	894	364	113	1,763	909
1946 to 1960	88	765	334	134	1,827	1,356
1961 to 1970	37	453	153	82	1,681	970
1971 to 1979	44	573	180	80	1,559	823
1980 to 1986	8	118	39	22	219	127

[a]The wall area was calculated as:
Wall area = 12 ft. (ceiling height) x 4 walls
x square root (total ft^2/number of floors)
x proportion non-glass exterior walls.

[b]The floor area was calculated (assuming equal size floors) as:
Floor area = total ft^2/number of floors.

Source: Energy Information Administration, Office of Energy Markets and End Use, Energy End Use Division, Form EIA-871A, "Building Questionnaire," of the 1986 Nonresidential Buildings Energy Consumption Survey.

makes it an excellent vehicle for the collection of baseline measurements on these issues.

As previously mentioned, on the 1989 CBECS EIA clarified the categorization of space-conditioning equipment so that chillers in particular could be more reliably identified. EIA also added a question on the age of the chillers and packaged air-conditioning equipment to the existing cooling questions. An additional question was added to determine the presence of other refrigeration units including: commercial refrigeration units, commercial freezers, residential-type refrigerators, residential-type freezers, ice-making machines, soda and other refrigerated vending machines, and water coolers.

Second, EIA expanded the scope of the survey to collect system-wide energy inputs and outputs from nonutility central plant facilities supplying electricity, steam, and district heating and cooling to any commercial building falling within the sample. Additional information from the Facility Form on the number and size of the chillers used on facilities, campuses or complexes will complete the picture of the contribution of commercial buildings to CFC usage in cooling equipment.

In addition to the regular tables on heating and cooling equipment used in the building, the 1989 Building Characteristics Report will include (subject to the statistical reliability of the data) at least the following new information useful in the analyses of CFC-related issues: (1) the age of the chillers and packaged units cross-tabulated by the year the building was constructed, and the square footage in the building and (2) the types of commercial refrigeration equipment cross tabulated by principal building activity, year of building construction, and square footage of the building.

Furthermore, the information on equipment vintage can be used to produce a special report on equipment life cycles. The 1989 data will only yield information on the age of existing equipment and, thus, would not be sufficient by itself for the determination of survival functions. However, the 1989 data would be a valuable complement to the new equipment production data already available from other sources. Beginning in 1992 the CBECS longitudinal panels (see below) will be another source of information on equipment turnover.

WHAT FUTURE CBECS MAY TELL US

The timing of the CBECS on three-year cycles offers both a longitudinal and cross-sectional view of changes in the building population over time.

Beginning with the 1986 CBECS, the sample was designed with a longitudinal component (i.e., a set of buildings that will be included in the survey twice) to allow the tracking of energy efficiency improvements in buildings. The buildings participating in the 1986 survey will be recontacted in 1992 and asked about replacements in equipment and other conservation steps taken since the 1986 survey. Demolition rates will be calculated and should prove useful in the development and testing of equipment life-cycle models. There is also a possibility for longitudinal analysis for the 1989-1995 and 1998-2003 surveys.

The 1992 sample will consist of two sets of buildings: (1) the set of buildings that were interviewed in 1986 and (2) a set of buildings that were constructed since the 1986 survey. The reinterviewed buildings will be asked about changes in general building characteristics such as size; occupancy and operational patterns; and energy-related characteristics (such as changes in fuel use, replacement of equipment, and conservation steps taken since the 1986 survey.)

Although the analysis of the 1989 data is just starting, the triennial survey schedule requires the planning of the content of the 1992 survey. Suggestions on the collection of additional data have already been received through extensive interaction with the various working groups and individuals using the CBECS data in support of DOE's work on the CFC and global warming issues and on the NES. There is a general consensus that EIA needs to collect more data on sector-specific consumption of energy; the market-penetration of alternative fuels such as solar, wood, geothermal, and biomass; the market penetration of energy-consuming equipment; and consumer equipment-purchasing decision making.

SUMMARY AND CONCLUSIONS

This paper illustrates the usefulness of data from the CBECS for understanding the scope of the problem of CFCs in commercial buildings. Using data on building characteristics from the 1986 CBECS, estimates were derived of the total amount of CFC 11, 12, 13, 114 and HCFC-22 used in commercial buildings. These estimates were found to be in reasonable accord with other production-based estimates. Less detail was available from the 1986 CBECS relative to CFCs for insulation and refrigerants but it was possible to provide some estimate of the possible extent of CFC usage.

The 1989 CBECS, currently being published, will provide some data on these issues, and there is still an opportunity to make the 1992 CBECS more useful for analysts of CFCs, and building-related environmental problems in general.

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