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Experimental Dwellings:
Modern Architecture and Environmental Research at the M.I.T. Solar Energy Fund, 1938-1963

Modernism and Environmentalism

The history of experimentation in solar energy for house heating at M.I.T. engages historiographic problematics of both modern architecture and environmentalism. Much as architectural historians identify—in the present volume and elsewhere—a 'second modernism' emerging out of the chaos of World War II, historians of environmentalism have developed a 'two-wave' schema. This is best articulated in Ramachandra Guha's *Environmentalism: A Global History*, in which he describes "an early period of pioneering and prophecy" read through literary transcendentalism and the wilderness idea, and, beginning after the war, "a second wave ... when a largely intellectual response was given shape by a groundswell of public support."[1] The "intellectual response" Guha describes involved the introduction of political and economic, scientific and managerial, and cultural and popular discourses into pre-war conservation and preservation movements. Though the war figures as an important fulcrum, the second wave is seen to be catalyzed by Rachel Carson's Silent Spring of 1963, which evoked in compelling prose a complex ecology of human-nature interactions. Carson's book is widely regarded as the fount of popular reaction to the out-of-control effects of industrialization, and at the same time it is understood to initiate the managerial disposition of the environmental sciences and the project of environmentalism as one of experts contributing to policy proposals and legislated regulatory regimes.

In recent years, much of this historical schema has been interrogated and reconfigured. Ted Nordhaus and Michael Schellenberger's "The Death of Environmentalism," written as a report for the Environmental Grantmakers Association in early 2005, indicates what is at stake in this regard. This text proposed that the scientific-policy-managerial model initiated by Carson's book had devolved into environmentalists acting as a special interest group concerned for "a supposed thing—the environment" rather than for "advancing a worldview" of connections between economies and ecologies.[2] As a result, environmental problems have been articulated as subject to technological fixes, and are often seen in isolation from the variety of social, cultural, and political issues that are embedded within them.

Nordhaus and Schellenberger's critique further suggests that the global project of recognizing ecological interconnection and advocating for environmental health has disregarded the profound effects of the environment and of environmentalism on the production of subjectivity. In what follows, I want to propose a historiographic analogue to "The Death of Environmentalism" by identifying the emergence of an environmentalist subjectivity in connection with the cultural developments of modern architecture, and in the form of a multivalent envisioning of alternative futures. Solar house experimentation at M.I.T. provides a window into political, economic, technological and architectural discourses immediately after World War II which sought to form a cultural response to the perception of depleting energy sources. Tropes of modern architectural design were deployed in an attempt to advance new subjects who desired different political and material conditions. These experiments provide a different genealogy of environmentalism at the same time that the close affinity between solar efficiency and the post-war transformation of modern architecture allows us to develop the history of modern architecture in a new and compelling context.

'A Strange Looking Little Building'

Solar energy experimentation at M.I.T. began before World War II with the establishment of the Godfrey L. Cabot Solar Energy Fund in April 1938. Cabot had made an identical gift to Harvard University in June of 1937, spurring Vannevar Bush, then Dean of Engineering and Vice-President of M.I.T., and Karl Compton, President of the Institute, to lobby Cabot to make a similar donation to their school. In order to limit possible overlap with the Harvard program, which was focused primarily on biological and agricultural applications, the M.I.T. funds were, according to the deed of gift, limited to "converting the energy of the sun to the use of man by mechanical, electrical, or chemical means without the intervention of plant life."[3]

For all three of these figures—Cabot, Bush, and Compton—the social responsibility of scientific inquiry was at stake. Cabot indicated surprise that, while the sun's energy had been available and marginally utilized for centuries, in the 1930s even the most advanced scientists did not know if effective large-scale utilization was possible. In correspondence with Compton, he proposed that both theoretical and applied research should be developed immediately to determine whether solar energy could replace fossil fuels in the relatively

1 Ramachandra Guha, *Environmentalism: A Global History* (New York: Longman, 2002), 3-7, 65. See also Paul Hawken, *Blessed Unrest: How the Largest Movement in the World Came into Being, and Why No One Saw it Coming* (New York: Viking, 2007); Samuel P. Hays, *A History of Environmental Politics since 1945* (Pittsburgh, PA: University of Pittsburgh Press, 2000) and Thomas Robertson, "'This is the American Earth': American Empire, the Cold War, and American Environmentalism" *Diplomatic History* 32, no. 4 (Sept 2008), 561-584.

2 Michael Schellenberger and Ted Nordhaus, "The Death of Environmentalism" *Proceedings of the Environmental Grantmakers Association* (October, 2004), np.

3 "Deed of Gift to the Massachusetts Institute of Technology by Godfrey L. Cabot '81," box 43, folder 16, M.I.T. Office of the President Records, Solar Energy Fund (AC 4), Institute Archives.

distant future. The Fund was thus established with a 50-year life span and its endowment divided between theoretical research and attempts "to determine whether the direct use of the sun's energy is now economically feasible, and if so, where and under what conditions."[4] The emphasis on the social and economic relevance of technological research—on applied science—corresponded to the goals of Compton and Bush, both strong supporters of scientific integration into industrial and legislative practices before, during, and after the war.

The early work of the Fund produced important applied results. Led by Hoyt C. Hottel, professor of Chemical Engineering at M.I.T., near-term experimentation focused on the production of a solar-heated structure designated as Building 34 on the M.I.T. campus.[5] As Hottel described it in 1940: "we have out on the back lot of the Institute a strange-looking little building, where we can study the performance of solar energy collectors and compare it with records of solar intensity, and where we can study the use of heat so collected."[6] Hottel's own drawings served as the initial 'design' of the building, its formal disposition being standard enough that, aside from the installation of scientific instruments, the details were left to the Institute's building contractors. **1** A one-story, two-room structure, Building 34 had an open attic and an enormous basement water tank for heat storage. Solar panels on the roof were organized in three modules, with different combinations of insulating material, glass facing, sealants, and other experimental parameters. A fourth module was reserved for measuring equipment so that the amount of sunlight received could be correlated to the amount of spatial heat produced.[7] 2

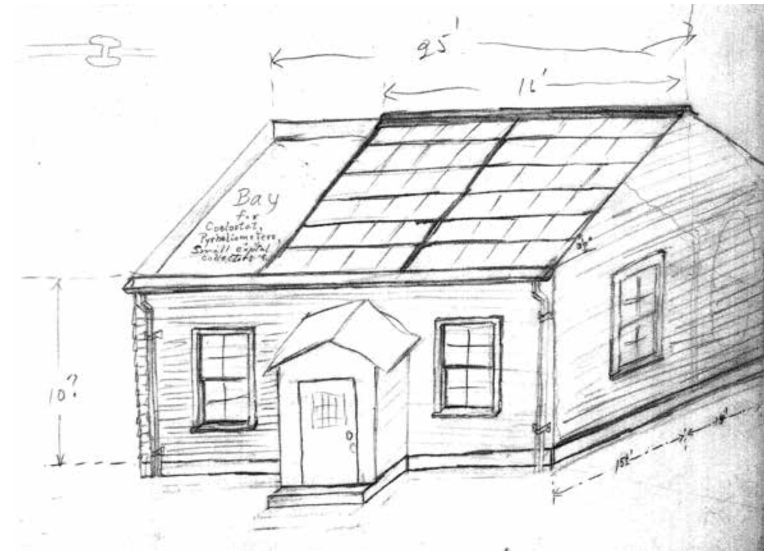
Three technological issues emerged. First, Hottel and his colleagues established the design and construction of the solar panel and the organization of its attendant system of space heating, producing a template that would be used by researchers, architects, and homebuilders until the late 1980s. The best panel they tested consisted of a wool-insulated base encased in wood and aluminum and covered by two panes of glass. 3 To produce heat, water was electrically pumped from the basement tank through copper tubing laid into the wool insulation of the panel. This water was then heated by solar radiation and returned to the tank. When required, air from the outside would be blown over the heated

4 V. Bush, et al, "A Research Program on Direct Utilization of Solar Energy" dated Sept. 25, 1937, box 43, folder 16, M.I.T. Office of the President Records, Solar Energy Fund (AC 4) Institute Archives.

5 The committee also included A. von Hippel (Electrical Engineering), Ernest Huntress (Organic Chemistry), A.C. Hardy (Applied Optics) and G.W. Swett (Mechanical Engineering). Letter Compton to Abbot, June 4 1938, box 43, folder 16, M.I.T. Office of the President Records, Solar Energy Fund (AC 4), Institute Archives.

6 Hoyt C. Hottel, "The Sun as a Competitor of Fuels," box 18, Hoyt C. Hottel Papers (MC 544), Institute Archives, 5. (hereafter 'Hottel Papers').

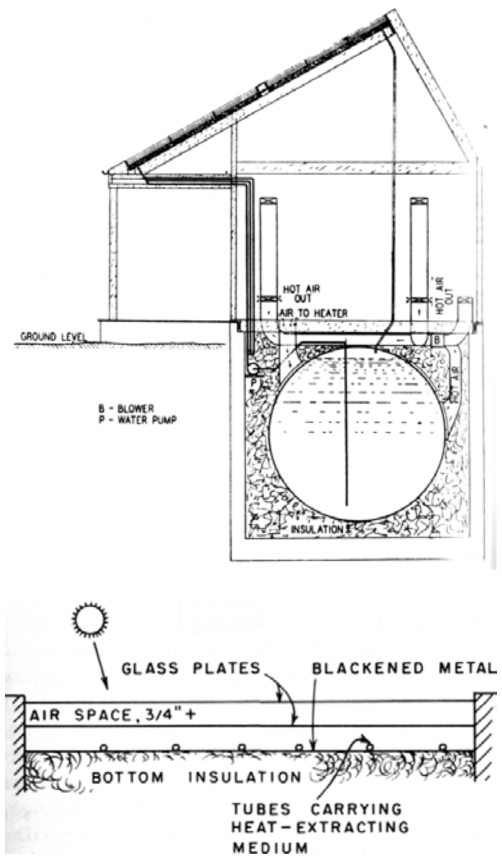
7 Memorandum, Hottel to Executive Committee of M.I.T. box 16, Hottel Papers. A map of the site that accompanied the budget request indicates that heat and hot water were to be made available from neighboring buildings, thus the panels were not to be exclusively relied on in this capacity.



1. Hoyt C. Hottel, drawing for Building 34, 1938, box 17, Hoyt Hottel Papers (MC 44), Institute Archives and Special Collections, MIT (hereafter Hottel papers).

2 MIT Solar Energy Fund, Building 34, Cambridge, MA, 1939. Installation of solar panels. Hottel papers.

3. MIT Solar Energy Fund, Building 32, Cambridge, MA, 1939; schematic of solar panel and heating system, including storage tank. From Hamilton, Space Heating with Solar Energy. (1954)



water and warmed, and then blown into the laboratory room. Using this system, Building 34 was able to maintain a temperature of 72° throughout the winter.[8]

Though effective, the system was expensive—three times the cost of a comparable fuel-based system. The storage tank was the most expensive component; the second technological issue—identified but not resolved at Building 34—was that of heat storage. The ability to store solar radiation was vital to the economic viability of solar heating and led to a wide variety of proposals after the war, as will be discussed below.

The third technological issue was that of determining the ideal angle of the collector. An important goal of the experiment was to establish the best method of measuring solar radiation in order to indicate the efficiency with which heat was produced; thus, careful attention was paid to the measurement devices. After exchanging data with the U.S. Weather Bureau, Hottel realized that the calibration 'constant' provided by the Bureau for a number of the measuring devices was "not a constant but a variable, dependent upon solar altitude."[9] In other words, the amount of solar insolation, and thus the efficiency of solar heating, was dependent on the solar rays' precise angle of incidence on the collector panel. Much of Hottel's work over the course of the subsequent decade would concern the refinement of a methodology for tilt-angle determination. More generally, these technological problems are indications of the necessity for a finely-tuned relationship between roof angle, heat storage, and internal volumetric disposition which would play out in the context of transformations to modern architecture after the war.

The First Oil Crisis

After the war, however, much else had changed. Concern over the depletion of fossil fuels greatly exacerbated the need for energy alternatives, and the urgency for demonstrating the economically viability of the solar house increased. While anxiety over resource scarcity existed before the war—as the establishment of the Cabot Fund indicates—a shortage in domestic heating fuel in the winter of 1947-48 increased these fears, and a dynamic discussion on resource scarcity ensued.[10] Already evident to the petroleum industry in June, by mid-November a heating fuel shortage had reached a crisis state, and *The New York Times* and other papers were writing daily updates on families struggling to keep their houses warm.[11] Falling temperatures at the end of January hinted at further catastrophes as snow-blocked roads and frozen waterways prevented available oil from reaching houses and apartment buildings. Chicago and the Midwest were also beginning to suffer.[12] *The Times* by this point had given up on help from the government and was resigned to a winter-long crisis; *The Chicago Tribune* began its own analysis of global oil distribution regimes and the roots of the supply problem.[13] 4

The crisis of 1947-48 catalyzed anxiety over the future supply of energy resources for the growing American economy.[14] The outlines of post-war growth were predicated on industrial development, full employment for returning soldiers, and a dramatic increase in the building stock. A reliable source of energy was necessary for all three of these goals. Wartime demands had made clear that the long-feared depletion of coal was becoming a reality. Expansion of hydro-electric power was also limited as these installments had been operating at capacity since 1942. Finally, much of the post-war increase in energy use was

8 August L. Hesselschwerdt, "Performance of the M.I.T. Solar House," in Richard W. Hamilton, ed., *Space Heating with Solar Energy: Proceedings of a Course-Symposium held at the Massachusetts Institute of Technology, August 21-26, 1950*, (Cambridge, MA: Massachusetts Institute of Technology/Bemis Foundation, 1954), 99. See also Austin Whillier, "Principles of Solar House Design," *Progressive Architecture* 36 (May 1955), 122-126. The panel is known today as the "Hottel-Whillier flat-plate collector."

9 Hottel in James J. Bohning, "Hoyt C. Hottel: M.I.T.'s Combustion and Solar Energy Pioneer" in *Chemical Engineering Progress*, Vol. 84 (March 1988), pp. 53-55. The definitive text on the subject is Hoyt C. Hottel and Bernard B. Woertz, "The Performance of Flat Plate Solar Collectors" in *The Transactions of the American Society of Mechanical Engineers* vol. 64 (1942), 91-104.

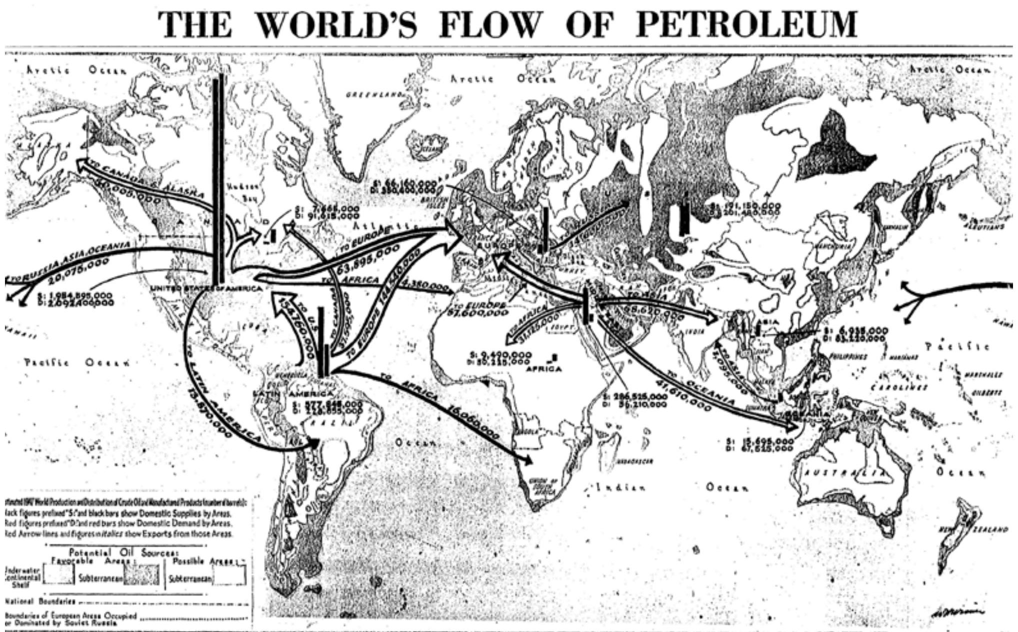
10 Richard H.K. Vietor, *Energy Policy in America Since 1945: A Study of Business Government Relations* (New York: Cambridge University Press, 1984), 91.

11 Walter H. Waggoner, "Fuel Crisis Looms, Army, Navy Assert," *New York Times*, June 19, 1947, 1-2. See also "Seek Oil Abroad, Industry is Urged," *New York Times*, November 13, 1947, 46; "U.S. to Propose Voluntary Oil Rationing," *Washington Post*, December 3, 1947, 9; and "Fuel Crisis Grows as Deliveries Lag," *New York Times*, December 30, 1947, 1, 4.

12 "Cold Deepens Crisis in Fuel Oil Shortage," *Chicago Daily Tribune*, January 23, 1948, 17.

13 "Oil Shortage All Winter is Predicted for East," *New York Times*, January 21, 1948, 1; Wayne Thomas and Stanley Johnston, "Why World is Short of Petroleum," *Chicago Daily Tribune*, January 29, 1948, 1, 8, back page. Note that the *Tribune's* map is an inaccurate assessment of

4 "The World's Flow of Petroleum" from The Chicago Tribune January 29, 1948.



focused on liquid fuels—especially for the automobile—in which coal (despite continued efforts to develop synthetic liquid fuels) and hydroelectric could not compete.

While its origins lay in anxiety over domestic reserves, the first oil crisis, in distinct contrast to the regional conservationist discourse of the 1930s, had ramifications across both geopolitical and geophysical registers.[15] By the end of World War II, U.S. oil companies had extensively penetrated the production systems of every major oil-producing region in the world.[16] At first, the market for overseas oil produced by U.S. companies was itself almost completely outside the U.S.; this was due to legislated protection of the oil industry still operating on U.S. soil and to the decimated resource base of Western Europe and its urgent programs of reconstruction. By early 1947 more than half of Western Europe's energy needs were supplied by U.S.-owned companies operating in the Middle East. The Marshall Plan, initiated in June of 1947, increased this figure. Cold War historian David S. Painter has argued that one of the most significant and lasting effects of Marshall Plan aid to Europe was the creation of a reliable consumer base for U.S. companies seeking to develop the oil fields of the Persian Gulf (an expensive investment in infrastructure costs) at a time when the American market was temporarily off-limits; this entry into the European market secured the prominent position of U.S. oil corporations in the world economy for decades to follow.[17]

In January of 1948, as the weather turned colder, global oil production was increasing but was not reaching American homes. No one had an economic incentive to provide the oil, and the Truman administration—looking to the election in November—was hesitant to do anything. By mid-February, falling temperatures and failing infrastructure made the situation so dire that they did everything: Truman ordered the Navy to divert reserves to the East Coast, solving the immediate crisis; simultaneously, oil exports were limited and import restrictions eased. As energy historian Richard H.K. Vietor notes, "these actions helped alleviate the heating oil crisis, but left a residue of permanently expanded imports … As of January 1949, imports were increasing by 25% a year." Vietor is one of many scholars to identify the winter of 47-48 as the start of net-importation in petroleum by the U.S., a condition which persists to the present.[18] The seemingly endless reserves of the Middle East, however, were not yet apparent to the oil industry or the American public, and while on February 19 The New York Times declared that "the East Coast is 'over the hump' with its fuel supply for the rest of the winter," projections for the long-term future remained bleak. As The Times had editorialized in late January: "the situation is indeed critical, especially when it is remembered that in ten years we shall be pinched for oil and our consumption of petroleum products is growing. The time is now to begin preparations for the future."[19] In the context of heightened Cold War anxieties and a deepening recession, the concern over heating fuel supply in the midst of a frigid winter sparked a feverish anxiety over the future of American prosperity.[20]

the relative production of oil in the U.S. Southwest, Venezuela, and the Middle East in this period, indicative of gaps in general knowledge.

14 The first oil crisis described here has not been historicized as such; its significance, all the same, is suggested in Frank Laird, *Solar Energy, Technology Policy, and Institutional Values* (New York: Cambridge University Press, 2001) and in relation to the technology of synthetic fuels in Vietor, *Energy Policy in America.*

15 See Harold Ickes, "We're Running Out of Oil!," *American Magazine* (Dec. 1943), 37-43; 38.

16 Edward DeGolyer, "Preliminary Report of the Technical Oil Mission to the Middle East," *Bulletin of the American Association of Petroleum Geologists* 28 (July 1944); 919-23.

17 David S. Painter, "Oil and the Marshall Plan," *Business History Review* Vol. 58, No. 3 (Autumn, 1984), 359-383; 362ff. More than 10% of the total aid provided by the U.S. for European recovery was spent on oil extracted and distributed by American firms; this was significantly more than any other single commodity.

18 Vietor, *Energy Policy in America*, 94.

19 "Fuel Crisis Ended Along East Coast," *New York Times*, February 19, 19947, 46; in other articles they addressed the emergency measures of Navy supply releases; see Charles Grutzner, "More Navy Oil, 300 Rail Cars Help Ease Fuel Famine Here," *New York Times*, February 12, 1948, 1, 4; "Impeding Oil Crisis," *New York Times*, January 22, 1948, and "Navy Allots Oil Supplies, Eastern Fuel Crisis Eased," *The Chicago Daily Tribune*, February 6, 1948.

20 The February 1948 coup in Czechoslovakia, along with Truman's loud denunciation of Soviet aggression in March, dramatically heightened tensions between the superpowers and also heightened public anxiety over the possibility of impending war; further, a recession in the U.S.

The Environmentalist Future

Looking at the twentieth century through the historical framework of environmentalism, the first oil crisis was a dramatic break. A fissure erupted in the conception of the globe and its material interconnections, and into it flowed a stream of intense economic, technological and cultural analysis which attempted to predict the outlines of future resource needs. On the one hand, this led to a heretofore incomprehensible drive for resource extraction and economic growth—what has come to be seen as the post-war consumer boom. On the other hand, a discourse on resource scarcity emerged that was concerned with coordinating policies of growth with the cultural imaginary of an alternative future—what can be articulated, despite its imbrication with normative agendas, as the emergence of contemporary environmentalism. A central experimental object of this latter disposition, as we will see, was the modern solar house.

Two strands of resource scarcity need to be briefly summarized before discussing these houses. The first was articulated by Harold J. Barnett, a staffer at the Department of the Interior, in the report Energy Uses and Supplies 1939, 1947, 1965 of 1948. In it, Barnett made a profound proposal for the relationship between economic growth and resource depletion:

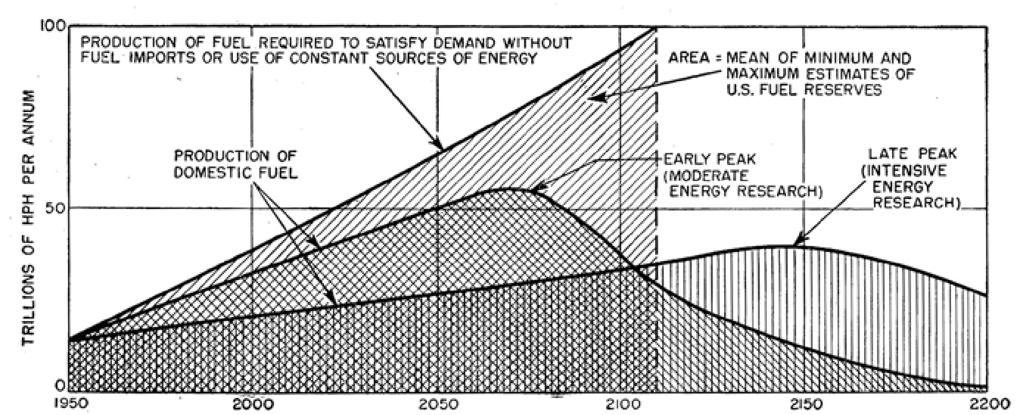
> If noticed before it has not been discussed in publication . . . [that] although the level of energy requirement is primarily determined by national product level, it is subject to secular fall because of efficiency gains in energy utilization. Advances in combustion efficiency, use of insulation, etc, occasion the downdrift. The tentative judgment is made, from knowledge that the most modern equipment is much more efficient than the average in use, that the downdrift will continue.[21]

In other words, Barnett suggested that while total energy use would continue to increase as the economy grew, the energy output per unit of Gross National Product would decrease as energy production became more efficient.[22] The way to avoid to resource scarcity, Barnett proposed, was to increase economic activity and thereby instigate industry development of methods to use existing supplies more efficiently.[23] As energy historian Craufurd Goodwin has noted, this report "contained a remarkably sophisticated treatment of energy statistics, and became the basis for most public statements about energy policy from the Interior Department for several years."[24]

Other voices expressed concerns over the eventual depletion of fossil fuels—even in the face in the massive reserves in the Middle East—and the need to develop viable replacements. Eugene Ayres, a research consultant for Gulf Oil, produced a widely read text on this subject. First presented as a speech to the American Petroleum Institute in 1948, "Major Sources of Energy," painted a bleak picture of existing reserves, and Ayres emphasized the technological and economic distinction between "continuous sources of energy," such as solar and wind, and "unrenewable sources of energy," such as nuclear and fossil fuels.[25] He contended that "the most important factor is not the size of a reserve but the rate at which it can be procured," a statement which initiated an important shift in conceptualizing resource reserves that produced a different balance sheet of energy uses and supplies which favored the development of renewables.[26] 5

Though both sides of this discourse were concerned with possible depletion, one, represented by Barnett, was focused on using technology to maintain the status quo and the other, represented by Ayres, was focused on developing technologies that would produce new forms of living. In many contexts—including, as will be discussed below, a 1950 symposium at MIT—Ayres emphasized the potential of architectural design in both the technological mitigation and the cultural imagination of alternative futures; regarding the former, in 1951 he wrote:

Figure 5 Eugene Ayres, "Some Possibilities in Our Future Energy Picture" from Eugene Ayres, Energy Sources – the Wealth of the World, (1952).



economy was developing throughout 1948 and continued into 1949. Lack of heat, fear of war, and an economic downturn coalesced to give the experience of fuel shortage somewhat more alarmist and even apocalyptic overtones. See Vietor, *Energy Policy in America*, 95.

21 Harold J. Barnett, *Energy Uses and Supplies 1939, 1947, 1965* (Washington, D.C.: Bureau of Mines, October 1950), 6.

22 Barnett, *Energy Uses and Supplies*, 6.

23 As Barnett would summarize in a later text: "While a fixed world always contains a threat of resource economic scarcity, nevertheless onset of scarcity depends on other conditions as well. So long as resources are large enough to permit out put expansion… resource economic scarcity is not yet experienced." Harold J. Barnett, *Malthusianism and Conservation: Their Role as Origins of the Doctrine of Increasing Resource Scarcity* (Washington, D.C.: Resources for the Future, Inc., 1958), 12-13.

24 Goodwin, "The Truman Administration," 37.

25 Eugene Ayres, "Major Sources of Energy," *Addresses and Reports Delivered at the Twenty-Eighth Annual Meeting,*

> We seem destined to become more and more dependent upon the sun for all energy. It happens that sunlight is somewhat more easily adaptable to space-heating than to the development of power. These two circumstances taken together are full of fortunate significance, for we actually require more energy for heating our homes and our places of work than for transportation or industrial power.[27]

In cultural terms, Ayres repeatedly cited the importance of "the dreams of our architects" in articulating alternative futures; moreover he placed the discussion in a moral context, proposing that "someday our appetite for energy will probably be satiated, and energy production will remain about constant … we shall have become a nation of philosophers."[28] These proposals and predictions would inform subsequent technological and cultural strategies.[29]

Both Barnett and Ayres influenced a number of subsequent developments. Their papers were frequently referenced at the United Nations Scientific Conference on the Conservation and Use of Resources (UNSCCUR) in the fall of 1949, which elaborated on these debates and also acted as a kind of international clearing house for their technological ramifications. Barnett's report served as the basis for Interior Secretary Julius Krug's welcome and introduction to the conference, while Ayres' proposal that the "host of technologists working constantly on problems of power production, transmission, and utilization" should focus their efforts on "continuous sources" was the acknowledged premise for the conference session on "New Developments in the Production and Utilization of Energy."[30]

In the face of increased depletion anxiety during the Korean War, President Truman established the President's Materials Policy Commission soon after UNSCCUR. The Commission's 1952 report Resources for Freedom foundered between the poles of the resource scarcity debate, attempting to follow Ayres' apocalyptic assessments of resource availability while also pursuing Barnett's techno-philic solutions.[31] This studied ambivalence was, in the end, of little consequence: Eisenhower, taking office in 1953, completely rejected the report—a rejection supported, we should note, by increased awareness of the extent of Middle East reserves, a CIA-led coup in Iran to further secure them, and considerable election donations from oil corporations. The call for government-funded research into alternative sources was ignored.

Chicago, Illinois, November 8 to 11, 1948 (New York: American Petroleum Institute, 1948), 109-144.
26 Eugene Ayres, "International Fuel Economy" *Annals of the American Academy of Political and Social Sciences* 281: The Future of our Natural Resources (May 1952), 73-78; 75.
27 Eugene Ayres, "Windows," *Scientific American* (February 1951), 60-65.
28 Ayres, "Major Sources," 144.
29 For other prominent advocates in this regard see Palmer Putnam, *Energy in the Future* (New York: Van Nostrand, 1953), based on a 1949 report to the Atomic Energy Commission, and M. King Hubbert, "Energy from Fossil Fuels," Science 109 (February 1949).
30 Ayres, "Major Sources," 110. See Julius Krug, "Introduction," in *Proceedings of the United Nations Scientific Conference on Conservation and Utilization of Resources: Volume I, Plenary Sessions* (New York: United Nations Department of Economic Affairs, 1951), 7; and "New Developments in the Production and Utilization of Energy" in *Proceedings of the United Nations Scientific Conference on Conservation and Utilization of Resources: Volume III, Fuel and Energy*

In the face of Eisenhower's rejection, and as an effort to maintain the thread of resource scarcity in the context of managing growth for the next few decades, a non-profit group developed directly out of the Policy Commission. Called Resources for the Future, the group absorbed the staff of the Policy Commission and lobbied for its policy imperatives.[32] Barnett came to play a significant role in the organization: his premise that technological innovation would save the day was reiterated in his 1963 text Scarcity and Growth: an Economics of Natural Resource Availability.[33] To a significant extent Resources for the Future is a prominent and early trace of the emergence of 'sustainability' as an environmental-managerial approach to economic growth, as later instigated by the popularity of Carson's text. In this regard it contrasts the alternative futures proposed by Ayres and his colleagues that informed the architectural discussions detailed below.

Experimental Dwellings

Modern architecture was also transformed by the war; in American architectural discourse this played out in large part through a discussion of the modern house and in terms of 'softening' the perceived technological determinism of the pre-war period. Joseph Hudnut, whose 1945 text "The Post-Modern House" rejected "those factory-built houses, pure products of technological research and manufacture, which are promised us," was concerned over both the "uniformity" the machine-made house presupposed and "the *promise of happiness*" it appeared to neglect.[34] His article proposed to rescue the formal innovations of modernism from the "enchantment of techniques" and return it to the realms of "shelter" and "space":

> The mighty cantilever which projects my house over the kitchen yard or a waterfall; that flexible wall and stressed skin; these fanaticisms of glass brick; these strange hoverings of my house over the firm earth – these strike my eyes but not my heart … If we wish to express in this new architecture the idea of home, if we wish to say in this persuasive language that this idea accompanies, persistent and eloquent, the forward march of industry and the changing nature of society, we have in the different aspects of space alone a wide vocabulary for that purpose.

Resources (New York: United Nations Department of Economic Affairs, 1951), 262-330; see also the documented discussion of the panel for indication of the debate between the two sides of the resource scarcity debate summarized here, 325-330.
31 See "President's Materials Policy Commission," *Resources for Freedom: Summary of Volume I of a Report to the President* (Washington, D.C.: U.S. Government Printing Office, 1952), 2-4. See also Palmer Putnam, "The Promise of Technology: The Possibilities of Solar Energy" in *Resources For Freedom: A Report to the President; Volume IV: The Promise of Technology* (Washington, D.C. US Government Printing Office, 1952), 213-220.
32 See Charles J. Hitch, ed., *Resources for the Future: The First 25 Years* (Washington, D.C.: Resources for the Future, 1977).
33 Harold J. Barnett and Chandler Morse, *Scarcity and Growth: An Economics of Natural Resource Availability* (Baltimore: Johns Hopkins University Press and Resources for the Future, 1963) as well as it's more data-focused companion volumes: Hans L. Landberg, Leonard L. Fischman, and

Hudnut articulated the principles of this promising spatial vocabulary in the precise formal and technological terms of the solar house that will concern us below, proposing that "our new structure and our new freedom in planning—a freedom made possible at least in part by the flat roof—has set us free to model space, to define it, to direct its flow and relationships."[35]

In the same vein, a symposium at the Museum of Modern Art in New York entitled "What is Happening to Modern Architecture" was held in February of 1948. Occurring at the height, as it happens, of the first oil crisis, though its effects are not directly evident in the proceedings, the symposium met to discuss a November 1947 *New Yorker* article by Lewis Mumford. Mumford's article applauded recent work in California as a "native and humane form of modernism … a free yet unobtrusive expression of the terrain, [and] the climate."[36] Flexibility of the roofline, careful volumetric organization, and a regionalist corrective to the 'international style' summarize the potent formal tropes of this second, softened modernism. Though Mumford was apparently unaware of research into solar housing, the elements he proposed both indicated the inherent modernity of the solar house and identify its potential role in developing a formal language for alternative dispositions of the industrial and social changes that Hudnut and others had also anticipated.

Furthermore, to an extent under-emphasized by the historiography of this period, the debates around this second modernism were played out at the Department of Architecture at the Massachusetts Institute of Technology. Many figures at the School of Architecture and Planning at the time were central to the discussion outlined above.[37] The techno-cultural milieu at M.I.T. provides evidence of the extent to which many issues which appeared contentious in published diatribes were integrated in pedagogy and practice; the modern house, in other words, was both a technological experiment *and* a spatially eloquent dwelling.

Thus when the Solar Energy Fund returned to work after the wartime hiatus, it engaged both the changing character of architectural research and an increasing concern over resource depletion. In early August of 1945, just as the war was ending, the Solar Energy Committee submitted a formal request to the president of the Institute to expand the Solar Energy Fund. The main new component was a Steering Committee for an Experimental Dwelling Project,

Joseph L. Fisher, *Resources in America's Future: Patterns of Requirements and Availabilities 1960-2000* (Baltimore: Johns Hopkins University Press and Resources for the Future, 1963).

34 Joseph Hudnut, "The Post-Modern House," in *Architecture and the Spirit of Man* (Cambridge, MA: Harvard University Press, 1949), 107-112; 108. The italics are in the original. The essay was first published in *Architectural Record 97* (May 1945), 70-75; i

35 Hudnut, "The Post-Modern House," 110-112. Here we read 'flat roof' as flexible roof-line, in relationship to a freedom of volumetric disposition as cubic volume of interior space for heating.

36 "What is Happening to Modern Architecture?" *Museum of Modern Art Bulletin* 15, no. 3, (Spring 1948), 4.

37 William Wurster—Mumford's model for the Bay Region Style—was Dean of MIT's School of Architecture and Planning from 1944-1950. Mumford, Hudnut, and Henry-Russell Hitchcock, who were all involved in these debates, were frequent visitors, as was R. Buckminster Fuller. See *President's Report 1946*, MIT

chaired by Professor of Architecture Lawrence Anderson.[38] With the introduction of this committee, the design of the house became a central focus in technological experimentation towards solar heating efficiency.[39] At the same time, the Solar Energy Fund's engagement with the Department of Architecture was also an engagement with the social and political anxieties of the first energy crisis, as Hottel noted in 1950:

> In bringing together representatives of the architectural and engineering professions to discuss solar housing, one has the difficult problem of measuring merit in two sets of units: the dollar suffices so long as the subjects is solar heating, but if the subject is solar housing there are included such considerations as cleanliness, health, freedom from concern over oil shortages or coal strikes, and aesthetic satisfaction. It is because of these dollar-imponderables that the problem is so much more an architectural than an engineering one.[40]

The inclusion of architecture represented, for the engineers already involved with the problem, an engagement with the cultural transformations embedded in the urgent need for new forms of energy.

This enthusiasm for architectural involvement, however, was overwhelmed by a need to refine the system of heat storage, as its expense threatened to handicap the economic viability of solar heating research. In March of 1946, a simple rectangle structure was built and dubbed the *Experimental Dwelling*. The south wall was the primary experimental site: completely glazed, its six panel modules faced interior "cubicles" with "a refrigerator-type door and heavy insulation separating them" so that each was thermally isolated.[41] The experimental issue was the relative effectiveness of using chemical compounds instead of water as a heat storage device, and each module contained a variation on a hybrid mechanism to collect and store radiant heat.[42] [figure 6] After eighteen months, it was determined both that chemical storage was no more efficient than water, and further that the construction and maintenance issues of the hybrid panel outweighed any potential heat savings.[43] A press release sent to the M.I.T. News Service in December of 1946, even before the second heating season of experimentation, was already apologetic, indicating that "the

Institute Archives, 38; see the *President's Report 1945-1953*, Institute Archives for an indication of this experimental milieu; see also Burnham Kelly, *The Prefabrication of Houses: A Study by the Albert Farwell Bemis Foundation of the Prefabrication Industry of the United States* (Cambridge, MA: MIT Press, 1951).

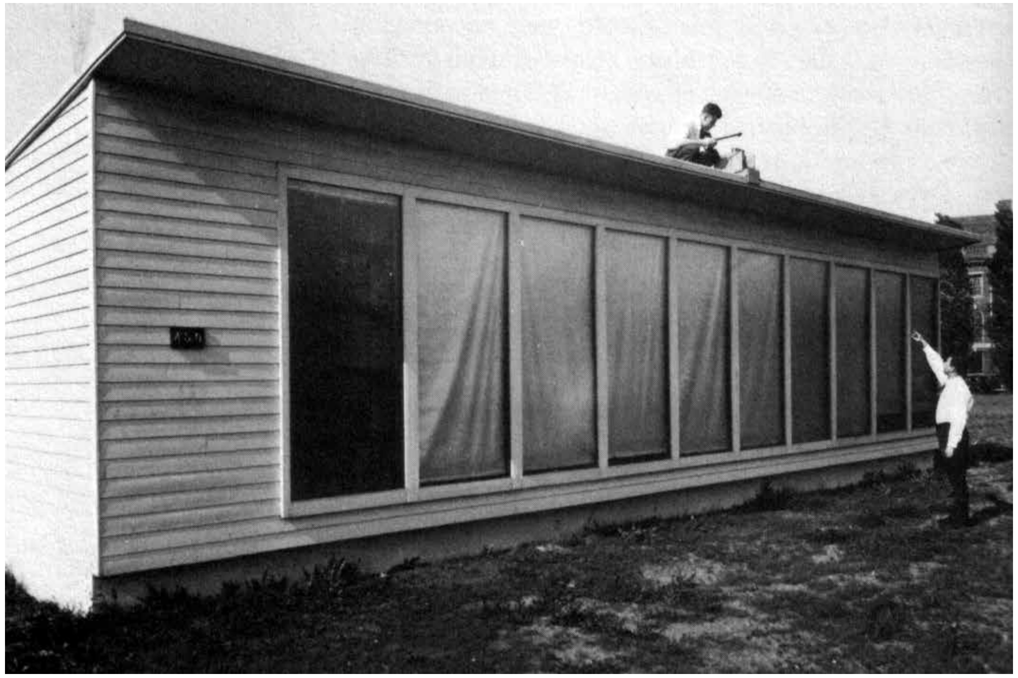
38 See Memoranda between Hottel, acting President James R. Killian, Wurster, and Anderson, August 8-21, box 43, folder 17, M.I.T. Office of the President Records, Solar Energy Fund (AC 4), Institute Archives. Anderson was a graduate of M.I.T. and had been teaching there since 1933; he was appointed to the position by Dean Wurster. He would go on to become head of the Department of Architecture in 1947, and to be Dean of the School of Architecture and Planning from 1965-1973.

39 Hottel, "Memo to Steering Committee on Experimental Dwelling Project," November 19, 1945, box 20, Hottel Papers.

40 Hoyt C. Hottel, "Introduction" in Hamilton, *Space Heating with Solar Energy*, 2-5; 2.

41 Hottel in Bohning, "Hoyt C. Hottel: Transcript of Interviews," 61.

42 This involved testing of the heat gain and storage capacity of Glauber's salts; at



6. MIT Solar Energy Fund, The Experimental Dwelling Project, Cambridge, MA, 1939; building with collector/ storage panels; interior view of monitoring equipment. From Popular Science, May 1949.

launching of this project does not constitute M.I.T.'s endorsement of this idea."[44] The first post-war experiment failed, and delayed the more extensive architectural involvement that was anticipated.[45] However, as will be seen below, this failed experiment held important consequences for the development of solar energy technology and the environmentalist impulses that surrounded it.

In the fall term of 1947 a fourth-year undergraduate design studio led by Anderson included a month-long competition on solar house design. In the brief, following a summary of the previous experiments, Anderson wrote, "It is believed that enough is now known to make desirable the construction of a small house." Anderson indicated that knowledge thus far gained had determined that the surface area of the collector and the square footage of the house needed to have a ratio approaching 1:1, and that "the architectural problem is that of reconciling the form of this collection and storage equipment to the usual and familiar requirements of a small dwelling without sacrifice to either."[46] Hottel's notes from the competition jury indicate good results. Though he dismissed a handful of entries as "unattractive," "poorly thought," or "hideous," a much larger number are celebrated as "original," "inspired," and "impressive." The winning entry, by John F. Haws, was described as "outstanding for the *number* of original ideas it contains."[47]

Despite these promising results, it was decided in July of 1948 that a renovation of the failed experimental building would be more expedient. The building was re-designed by Haws in order to provide "comfortable modern living facilities for a family of three," with an open living, dining and kitchen area, a small bathroom with a shower, a child's room, and a master bedroom.[48] The windows on the south wall were all triple-glazed to retain passive solar radiation.

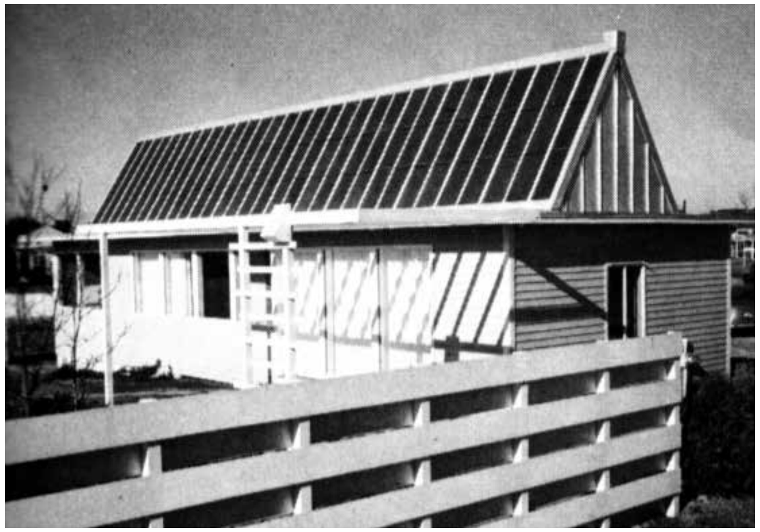
90ºF these salts melt and the 'heat of fusion' is absorbed and stored in liquid form. When the temperature drops, the compound re-crystallizes and the heat is released.

43 See Maria Telkes, "Solar House Heating – A Problem of Heat Storage" in *Heating and Ventilating* 44 (May 1947), 68-75.

44 Press Release, "Solar Energy Building," December 5, 1946, box 27 Hottel Papers. See also "Solar Energy Committee Meeting 22 September, 1947," box 27, Hottel Papers.

45 Letter, Hottel to Anderson, July 3, 1947, box 27,Hottel Papers. Hottel would later reject out of hand any system that proposed collection and storage in one unit as inefficient, receiving with some surprise information on Felix Trombe's experiments later in the 1950s. Hottel in Bohning, "Hoyt C. Hottel: Transcript of Interview," 73ff.

46 L.B. Anderson, "Grade IV Arch Design Fall Term 1947, Problem #3: A Solar House," There was a precisely calculated southern overhang to the roof which was supplemented by shade trees and vines strategically placed on the property to increase shading in the early fall and minimize it in the early spring.[49] A 1949 press release announced the house as "in appearance a typical modern-style residence except for its heat collector in the roof" [figure 7].[50]



7, this page; MIT Solar Energy Fund, The MIT Solar House, 1948. Hottel papers.

facing page: The MIT Solar House, from the Saturday Evening Post, 1949.

The angle of this collector, of course, followed Hottel's precise tilt-angle calculations. On the template of the *Building 34* system, water was circulated in copper tubes which ran behind blackened copper collector plates, themselves faced with two layers of glass. The panel was backed by aluminum and four inches of wool insulation. The copper tubes carried the heated water into a 1200 gallon heavily insulated water tank within the A-frame structure; a pump then circulated water from the tank through the heat collector "whenever the temperature of the latter is more than 5°F greater than that of the water in the storage tank." The stored heated water was then pumped through copper tubes embedded in the ceiling, providing radiant heat to the space below; the pump responded to thermostat controls in the living room and was automatically triggered when the interior temperature

box 58, Hottel Papers.
47 Handwritten note headed as "Comments of HCH on Architecture Department Contest on Solar House, Design, 1947," box 58, Hottel Papers. Emphasis in the original.
48 Brochure written by Anderson entitled "Solar House Heating: Part II: The M.I.T. Solar House," December, 1952, box 58, Hottel Papers, 3. Haws was the attributed architect of the house in all of the press releases.
49 Anderson, "Solar House Heating: Part II: The M.I.T. Solar House," 3.
50 Press Release, "The sun is substituting for a furnace in New England's newest home," February 13, 1949, box 43, folder 17, M.I.T. Office of the President Records, Solar Energy Fund (AC 4), Institute Archives.

dropped below 72°. There was an electrical heater in the water tank to supplement the solar heating of the water when necessary, and if the interior temperature dropped below 70° an auxiliary electrical heating system, located above the windows on the south wall, would also be activated [figure 8]. The solar heating system provided for 80-90% of heating requirements; these auxiliary measures supplied the rest.[51] The house was widely regarded as a successful example of alternative energy utilization in both experimental and pragmatic terms. The 1949 press release quotes Hottel as follows: "It is not now presumed that solar heating will be economically feasible in a climate as cold as that of New England, but the results should serve to indicate under what conditions of climate solar heating is competitive with fuel, oil, gas, or coal;" the specifics of this inquiry and the application of its experimental results would be taken up at great length in the years that followed.[52]

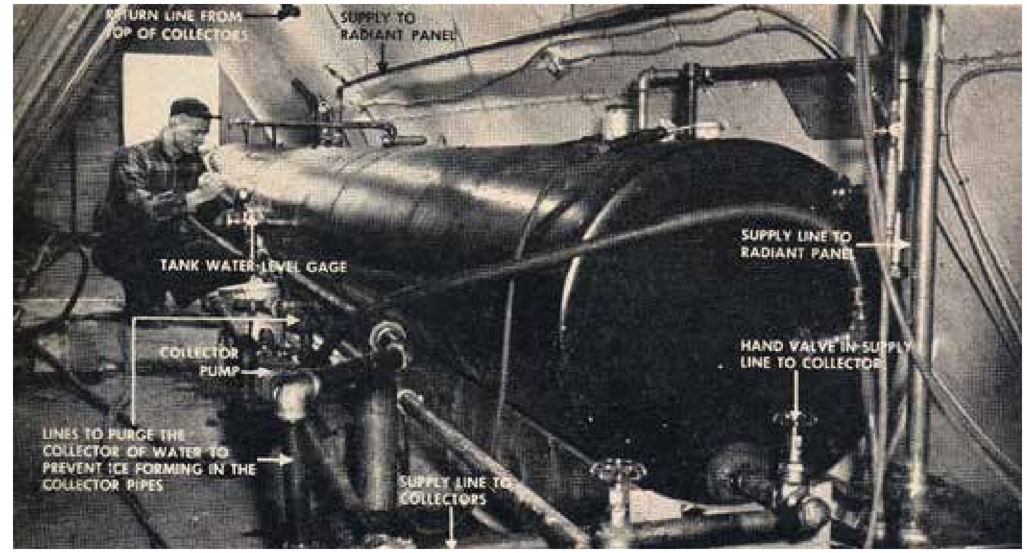
The Modern Solar House

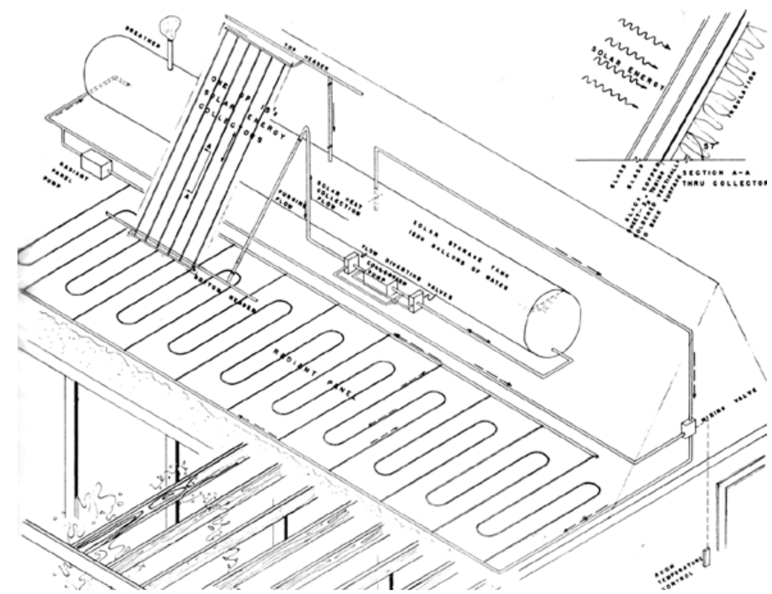
Interest in this third experimental building, which came to be known simply as the *M.I.T. Solar House*, was capitalized upon in a 5-day "Course-Symposium" on "Space Heating with Solar Energy" sponsored by the Cabot Fund in August of 1950. Attended by architects, politicians, scientists, journalists and others, the symposium expanded interest in solar house experimentation and drew direct connections between the spatial possibilities of modern architecture, the technological discourse on space heating, and the anxiety over resource scarcity. It thus provides early historical evidence of a multivalent cultural, technological and political form of environmentalist research. Much as the M.I.T. collector panel in 1938 established the technological foundation for later experimentation, the 1950 Course-Symposium provided a framework for the multiply-implicated discourse on solar architecture and served as an important reference point for its proliferation over the course of the rest of the decade.

Eugene Ayres began the proceedings with a discussion of "The Importance of Solar Energy" that drew from his "Major Sources of Energy" paper of 1948. He presented data outlining the increasing disconnect between energy demand and availability and proposed that existing fossil fuel sources would last only another 50 years. This, then, was the time frame for refining solar technology:

> Fifty years may seem like a long time … but history has shown that it has often taken that long to commercialize large scale projects, and during this 50 years there will be a continuous evolution of technology … Those who labor towards this most important end must not be discouraged by the flood of oil coming out of the ground, as this is also a transitory problem.[53]

Reiterating his 1948 proposals described above, he outlined the problems of wide application of solar technology on both technological and political terms, and proposed an urgent need to dedicate economic and land resources to large-scale experimentation.



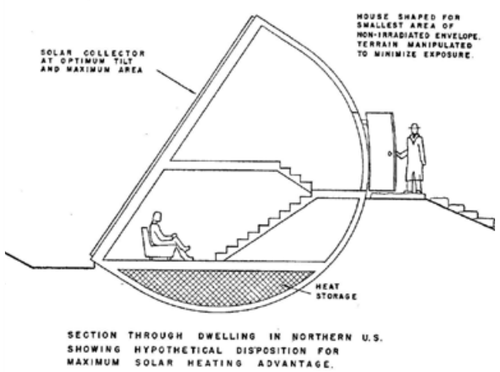


8. above; MIT Solar Energy Fund, The MIT Solar House, 1948. From Hamilton, Space Heating with Solar Energy (1954).

right, MIT Solar Energy Fund, The MIT Solar House, 1948. Schematic of system, photograph of tank. From Popular Science.

51 Anderson, "Solar House Heating: Part II: The M.I.T. Solar House," 3-4.
52 Press Release, "The sun is substituting," 1.
53 Eugene Ayres, "The Importance of Solar Energy," in *Space Heating with Solar Energy*, ed. Hamilton, 13.

9, top: Lawrence Anderson, "Idealized house..." from "Solar Heating Design Problems" in Daniels and Duffie, Solar Energy Research, (1953; **bottom:** Lawrence Anderson, Solar House Types, from "Architectural Problems" in Hamilton, Space Heating with Solar Energy, (1954[1950])



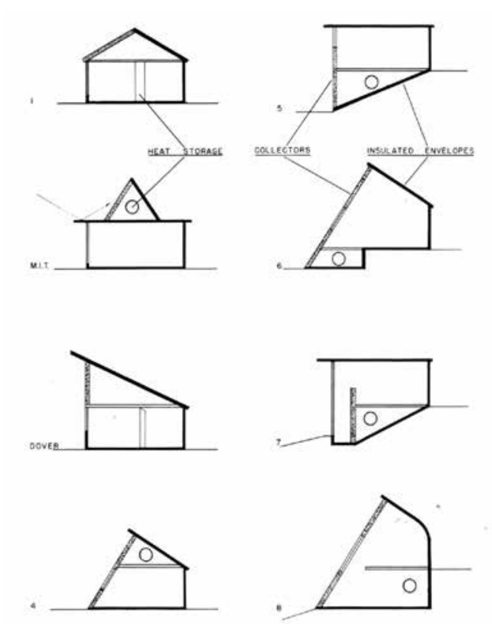


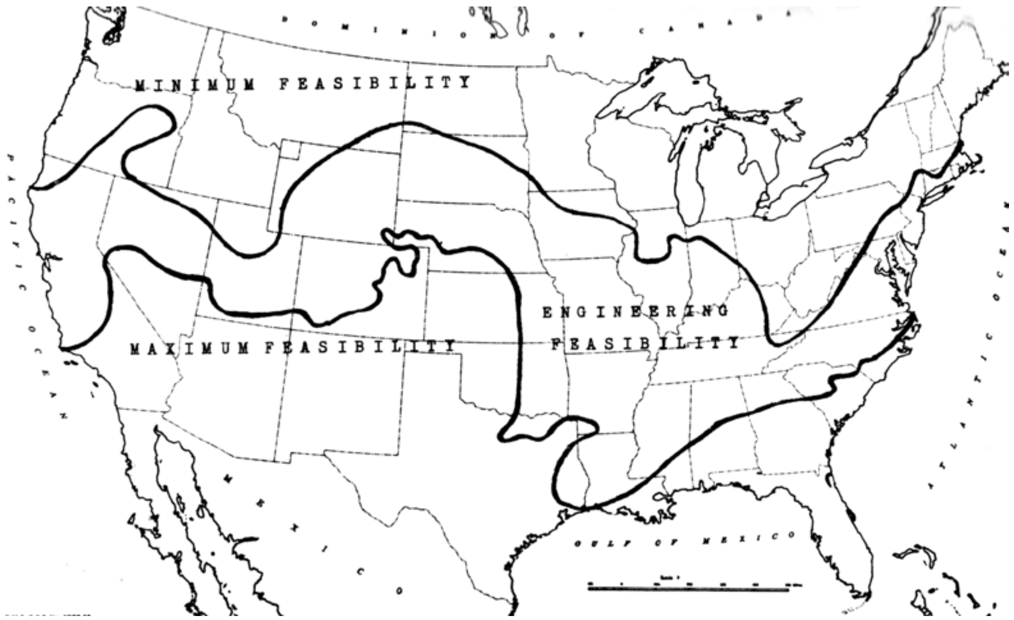
Figure 2. Solar House Types.

Reports on solar house heating experiments took up much of the conference program. Hottel presented three papers: the first outlined the basic parameters of panel operations developed in *Building 34*, the second discussed the *M.I.T. Solar House* in detail, and the third apprised the audience of previously published research on the issue of tilt-angle. Other houses were also discussed. Maria Telkes and the architect Eleanor Raymond both made presentations on the *Dover Sun House*, built in 1948 outside Boston, which used the chemical storage process of the second MIT House. It was dismissed as "over-engineered" by Hottel and was subject to much interrogation by the audience.[54] George Löf, an engineer involved in solar energy research at the University of Colorado, presented his "overlapped-plate collector," a proposal for increasing the solar absorption of the panel by using panes of glass painted black on one side and partially overlapping each other.[55] Löf also presented plans and models for a proposed house in Denver designed with the architect Peter Hunter.

While a presentation by George Fred Keck indicated the identification of passive solar design and the modern house, the Course-Symposium was more significantly the site for integrating technological and architectural strategies to optimize solar-engineered possibilities. These principles were developed through Anderson's presentation of typological analysis of the modern architectural characteristics of technologically refined solar houses. In his paper, "Architectural Problems," Anderson identified the relevant factors, including exposure of the south-facing façade, the relationship of collector to storage area, the volumetric characteristics of the enclosed space, the use of thermally absorbent materials, and the flexibility of the roofline to maximize solar collection. He presented a diagram of 'Solar House Types' that progressed from traditional design and low solar efficiency to modern design and maximum efficiency.[56] Anderson later developed these schematics into an "idealized house" that rejected both "convention and practicality of construction" in order to "have maximum collector area with optimum tilt and minimum non-irradiated area."[57] [figure 9] In this later article, Anderson wrote that "every architect should know how to design for the most favorable climatic response of his enclosure so that, other factors being equal, he will minimize summer discomfort, require less fuel during temperature extremes, or extend the zones in which no mechanical equipment is required."[58] Anderson proposed, in other words, that the architectural discourse on the post-war house should be engaged, as a matter of course, in the discourse on energy efficiency; a corollary, reflected throughout the symposium proceedings, suggested that the solar house could take advantage of the broader cultural interest in modern living. Conflating architectural and technological contexts, the Course-Symposium made it clear that the design parameters of solar heating required modernist architectural developments to maximize both solar absorption (through a flexible roof angle) and space heating efficiency (through carefully designed volumetric arrangements) in order to articulate a cultural object of solar-activated space.

Indeed, as George Löf wrote in the "General Significance and Summary of the Course-Symposium" that closed the published proceedings, the symposium's success lay in its definitive determination "that the flat-plate solar collector, in some form, is the most promising device for space heating with solar energy." The symposium also made clear, Löf proposed, that the promise of the collector was "closely associated with an architectural problem."[59] A brief though vibrant proliferation of the modern solar house was thereby instigated: the 1950s saw numerous federal, university, and privately funded programs as well as individual experiments. Most prominent was a competition for a solar-designed house in 1957-58 called "Living with the Sun," sponsored by the Association for Applied Solar Energy (AFASE), an offshoot of Resources for the Future that was founded in 1954. The published entries from the competition are both an important catalogue of solar design and a compendium of the domestic vocabulary of a second modernism.[60]

54 Maria Telkes, "Performance of the Solar Heated House at Dover," in *Space Heating with Solar Energy*, ed. Hamilton, 95.
55 George Löf, "Performance of Solar Energy Collectors of Overlapped-Plate Type," in *Space Heating with Solar Energy*, ed. Hamilton, 72-87; discussion on page 86.
56 Lawrence B. Anderson, "Architectural Problems," in *Space Heating with Solar Energy*, ed. Hamilton, 108-116, and Anderson, "Variables Affecting Solar Incidence," in the same volume, 17-24.
57 Lawrence B. Anderson, Hoyt C. Hottel and Austin Whillier, "Solar Heating Design Problems," , *Solar Energy Research*, eds. Farrington Daniels and John Duffie (Madison, WI: University of Wisconsin Press, 1955), 47-56; 49.
58 Anderson, et. al., "Solar Heating Design Problems," 48.
59 George Löf, "General Significance and Summary of Course-Symposium," in *Space Heating with Solar Energy*, ed. Hamilton, 153. Note that the proceedings were not published until 1954.
60 See John I. Yellott, ed., *Living With the Sun: Sixty Plans Selected from the Entries in the 1957 International Architecture Competition to Design a Solar-heated Residence* (Phoenix, AZ: Association for



10. Paul Siple, "Feasibility of Solar Heating Systems" in Hamilton, Space Heating with Solar Energy, (1954 [1950]). [Developed from graphics presented in House Beautiful, August, 1949.]

All the same, the large-scale viability of solar energy relied on shifts in the economic and political costs of fossil fuel exploitation. Right after Ayres' opening presentation at the 1950 Course-Symposium, Paul Siple, a geographer for the U.S. Army, presented a map of the U.S. which was divided into three uneven regions of "Maximum Feasibility", "Engineering Feasibility", and "Minimum Feasibility" for solar heating applications.[61]10 Siple's map was the subject of heated discussion. Löf first interrogated the speaker as to whether he had included fluctuating costs and regional availability of heating fuels in determining his contours. Siple replied that he had not. Hottel then asked for a more precise indication of how the distinctions had been drawn, to which Siple is reported to have indicated "that he had no exact formula but had combined the numerous data in an arbitrary manner based on average conditions" and conceded that "the curves could perhaps be considered as 'mechanical feasibility' curves as economic considerations were not included."[62] The animation of this discussion reflects the tension around being discouraged, as Ayres had put it, "by the flood of oil coming out of the ground." Solar house advocates–as proto-environmentalists–insisted on the increasing economic costs and long-term political risks of investment in fossil fuel infrastructure. However, in the face of a rapidly growing consumer culture dependent on this infrastructure and the expansion of military and bureaucratic apparatus intent on securing foreign oil, Anderson, Hottel, Löf and their colleagues were unable to turn back the flood of oil, or even to construct any bulwarks against it.

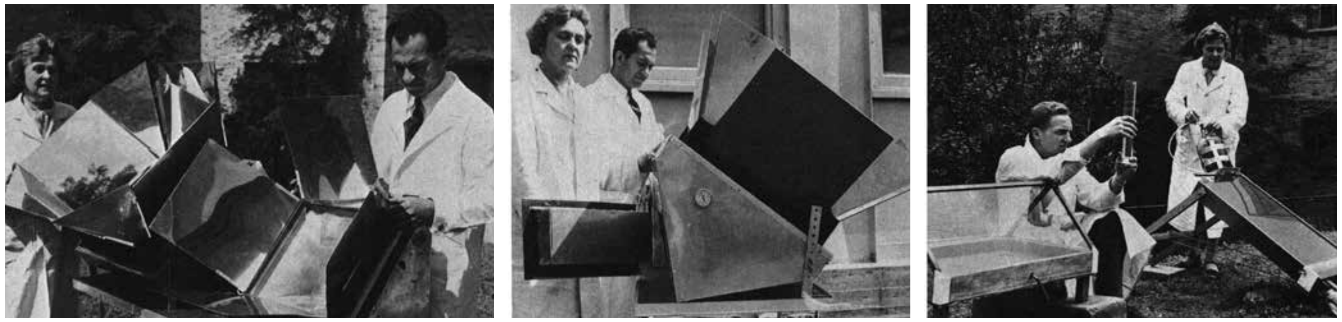
Applied Solar Energy, 1958).
61 Paul Siple, "Climatic Considerations of Solar Energy for Space Heating," in *Space Heating with Solar Energy*, ed. Hamilton, 14-16. Much of the data he developed was based on the "Climate Control" studies of *House Beautiful* in the late 40s; see Adam Rome, *The Bulldozer in the Countryside* (New York: Cambridge University Press, 2001).
62 Paul Siple, "Climatic Considerations," 16.
63 Farrington Daniels, "Introduction" in *Proceedings of the World Symposium on Applied Solar Energy* (Menlo Park, CA: Stanford Research Institute, 1956), 11. OLD: Phoenix, AZ: Arizona State University and the Stanford Research Institute, 1955), 3.

Modernization and Environmentalization

The ambivalent success of solar house heating was overcome by another site for the proliferation of solar energy technology in the 50s. Alongside – rather than despite of or in resistance to – the flow of oil, the use of chemical compounds as heat storage devices was developed as part of global industrial development regimes, with great consequences for the construction of systems of environmental management. The solar process that had been tested and that had failed in the second M.I.T. Solar House, the so-called *Experimental Dwelling*, was revisited in the early 1950s as energy concerns migrated from the American suburbs to the industrial development of the emerging third world. Here, solar energy was seen as a promising "complementary resource" which could lead to devices for improving living conditions in these under-industrialized countries. This also conveniently made the fossil fuels and other resources of these countries available to the industrialized north.[63]

Maria Telkes, the M.I.T. researcher who had spearheaded the use of chemical storage technology in the *Experimental Dwelling*, was the main figure in this research. Telkes had been hired into the Solar Energy Fund at its initiation on the basis of her work with thermocouples and their potential contributions towards the direct conversion of solar energy to electricity. During the war, Telkes and Hottel collaborated on solar desalinization units for downed pilots under the Office of Scientific Research and Development (OSRD). She was the driving force behind the Glauber's salt experiments at the *Experimental Dwelling* described above. She also had become good friends with Cabot and, blaming the failure of phase-change technology on Hottel, attempted to wrest the Fund's management from him in 1949. Instead, Cabot helped her secure funding for the *Dover Sun House*. Though it only worked for four years, the Dover house was initially seen as a "historic portent" of technologies to come. In 1953 Telkes left M.I.T. for N.Y.U., creating the "Solar Energy Research Center" in its College of Engineering and maintaining an important presence in the solar energy discussion for the following decades.

11; "The Solarometer, which can depict the angle at which the sun will shine on any house in North America at any given time, being discussed at the M.I.T. Symposium on Space Heating with Solar Energy; left to right: Professor Lawrence B. Anderson, symposium chairman; Dr. Maria Telkes, owner of the solar house in Dover; Dr. W.J. Arner of Libby-Owens-Ford Glass Co,; and George Fred Keck, Chicago Architect." August 1950, by Maynard White. M.I.T. Historical Collections.



Indeed, though the *Experimental Dwelling*, the *Dover Sun House*, and the later *Princeton Sun House* were plagued with operational problems, Telkes was able to use these experiments to advance a discourse around the possibility of solar energy as a viable energy source. Through promotion of the phase-change process at UNSCCUR and Resources for the Future meetings (when the Dover house was still operational), Telkes became a prominent solar energy consultant who worked on an array of development projects organized through N.Y.U., private foundations, and the United Nations "Technical Assistance" programs. The "invention of technical assistance" was part of the postwar reconfiguration of global co-operation initiated in the first General Assembly of the United Nations, which clarified the organization's "non-political functions" in terms of the "interrelatedness of social, cultural, political, and technical-economic change."[64] A resource focus to technical training became a major element of the global managerial regimes organized around the U.N. This was especially the case after the implementation of the "Expanded Program of Technical Assistance" (EPTA), which reached out beyond the war-torn conditions in Europe and Japan and into Africa, the Middle East, South America, and the Indian subcontinent, in 1951.[65]

12; Maria Telkes demonstrating phase-change solar ovens for export, New York University's Solar Energy Labarotory, 1956. From NYU Annual Report from the College of Engineering, (1956) in Maria Telkes Archives, Solar Energy Collection, Arizona State University.

64 Ruben P. Mendez, "United Nations Development Programme," http://www.yale.edu/unsy/ UNDPhist.htm. Mendez is quoting U.N. resolutions 53(I) and 133(II). 1; see also the discussion of technical assistance in Paul N. Edwards, "Meteorology as Infrastructural Globalism" in *Osiris* 21 (2006): 229-250; 241-244.

65 Everett E. Hagen, "A Framework for Analyzing Economic and Political Change," in *Development of the Emerging Economies: An Agenda for Research* (Washington, D.C.: The Brookings Institution, 1962), 1-44; 7.

66 A summary of these technological efforts, along with many others, can be found in Farrington Daniels and John Duffie, eds., *Solar Energy Research* (Madison, WI: University of Wisconsin Press, 1954).

67 UNESCO, *Wind and Solar Energy* (New York: United Nations Publications, 1955) and United Nations, *Proceedings of the United Nations Conference on New Sources of Energy: Solar Energy, Wind Power, and Geothermal Energy, Rome 21-31 August, 1961* (New York: United Nations Publications, 1964). A re-edition of the solar discussion in Rome, introduced by then-prominent solar technologist, Steve Baer, was published as *Solar 2: The U.N. Conference on New Sources of Energy* (Seattle, WA: Cloudburst Press, 1978).

Telkes became one of the first environmental experts. Her lab developed solar ovens for smoke-free cooking, solar distillation units to make sea water drinkable and usable for crops, small solar furnaces, systems for solar irrigation, agricultural frost protection, and the solar heating of oil pipelines to help the oil flow more smoothly. Her lab's research also explored the solar generation of electricity through heat engines and developed numerous methods to increase the efficiency of photosynthesis for the production of algae as a food source [12].[66] The affinity between the small-scale, low-cost, and relatively low-tech solar energy devices and the processes and goals of technical assistance resulted in a proliferation of ideas around chemical and other solar-storage methods in the 1950s. Telkes' expertise was on display at a number of conferences, including the UNESCO and Ford Foundation sponsored "Wind and Solar Energy" in New Delhi in 1954 and the "United Nations Conference on New Sources of Energy: Solar Energy, Wind Power, and Geothermal Energy" in Rome in 1961.[67]

The globalization of the environmental discourse from this period depended heavily on the conceptual formulation of "technical assistance" by western European and American industrialists and bureaucrats, especially as it became engaged with the complications of industrial development in tropical regions. The importance of developing these regions, especially in the context of "the 'rainforest connection'," as the environmental scientists Peter Taylor and Frederick Buttel call it, "has been central in the scientific and popular construction of global-change knowledge."[68] As they also point out, one of the major goals of the NGO-based environmental-protest and reform regime that emerged in the 1950s was "to influence, and to employ the influence of, the international development and finance assistance establishment, particularly the World Bank/IMF (International Monetary Fund), because of the important role of these institutions in affecting economic activity in the tropics."[69] Solar energy played an important if "complementary" role in the construction of these managerialist impulses.

At the same time, modern architecture played a significant and woefully under-analyzed role in the articulation of global strategies for economic and social development.[70] The contemporaneous emergence of a discourse around "Tropical Architecture" through a

68 Peter Taylor and Fred Buttel, "How Do We Know we have Environmental Problems: Science and the Globalization of the Environmental Discourse." *Geoforum* 23, no.3 (1992), 410.

69 Taylor and Buttel, "How Do We Know," 411.

70 For primary documentation of the interest in tropical dwellings, see Building Research Advisory Board, *Research Conference Report #5: Housing and Building in Hot-Humid and Hot-Dry Climates, November 18 and 19, 1952* (Washington, D.C.: Building Research Advisory Board, Division of Engineering and Industrial Research, National Research Council, National Academy of Sciences, May 1953) and Douglas H. K. Lee, *Physiological Objectives in Hot Weather Housing: An Introduction to the Principles of Hot Weather Housing Design* (Washington, D.C.: Housing and Home Finance Agency, June 1953).

13; Maxwell Fry and Jane Drew, Headquarters of British Petroleum. Lagos, Nigeria, 1960. From Victor Olgyay, Design with Climate, (1963).

group of architects, scientists, and sociologists in the UK in the early 1950s, applied the principles of architectural modernism to the climatic challenges of the global South.[71] The Tropical program produced its own scientific-managerial context in relation to a global climatic and resource system. As a result, Tropical Architecture was rather intensely focused on articulating a highly functional passively-cooled building, a sort of bare-faced pre-brutalist aesthetic of technological directness and climatic management here deployed to facilitate the continued economic growth of the former colonies 13. Though based, as one paper presented at the 1953 Tropical Architecture conference in London put it, on a sun-shaded "Anti-Solar House," these methods developed in tandem with that of solar house heating; both methodological innovations proposed the reconfiguring of the architectural project as a way of resolving contradictions of energy and economic development. It is here in the construction of environmental expertise, perhaps, as much as in the direct impact on solar house heating, that the experiments discussed above acquire historical significance.

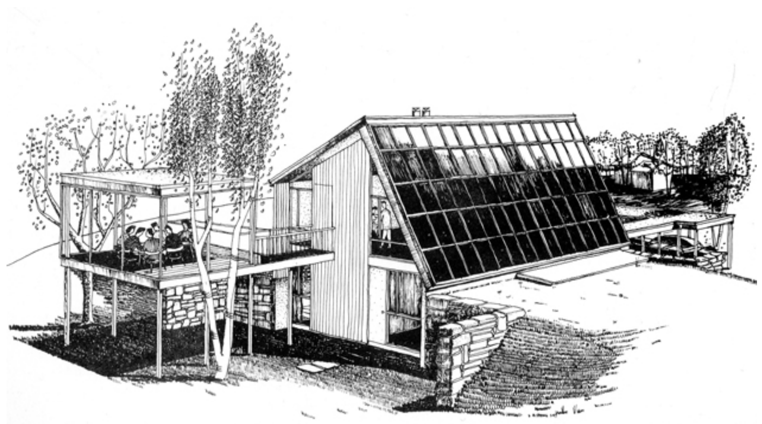
There were more solar houses in the 1950s. A fourth M.I.T. solar house was designed by Anderson in 1956 and built in 1958; by this time, the economic logic of the solar house had suffered considerably in comparison to initial interest following the first oil crisis. The infrastructure of oil had come to dominate post-war American suburban expansion.[72] *House IV* was built according to one of Anderson's ideal solar types, bermed for increased insulation and lined with a solar collector across its entire south-facing façade. 14 The system used three storage tanks of different sizes to manage the heating load most efficiently and, rejecting the radiant system of House III, returned to the blown-air system of *Building 34*. It worked marvelously, providing heat during the winter and hot water throughout the year.[73]

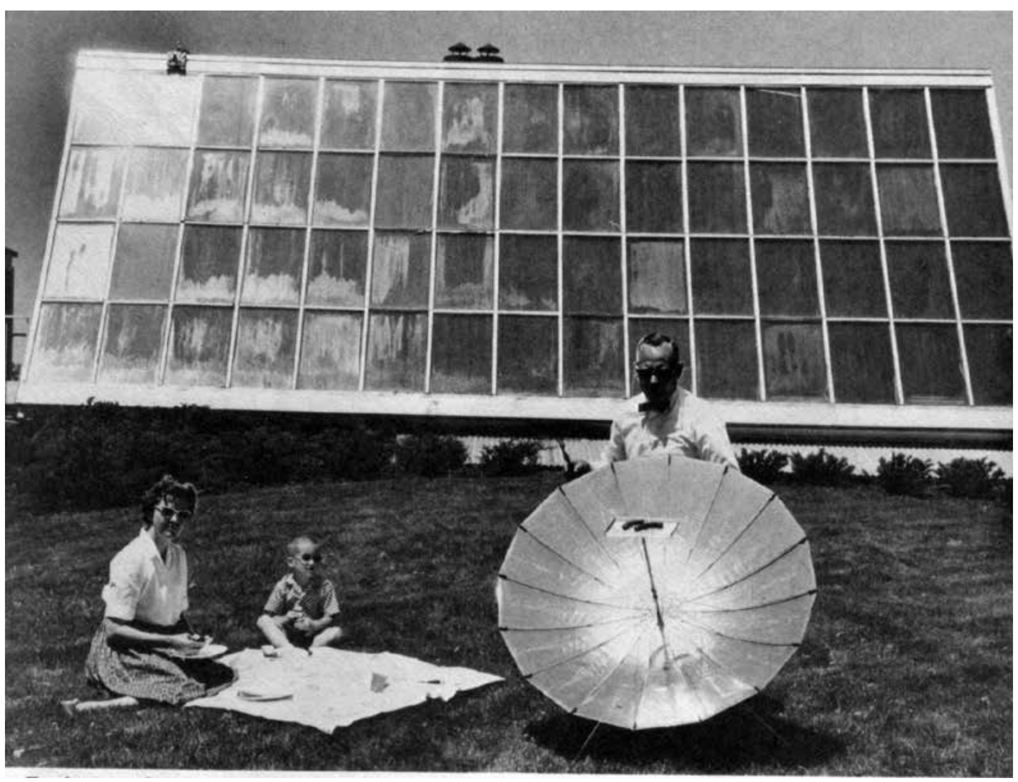
71 Maxwell Fry and Jane Drew, *Village Housing in the Tropics* (London: L. Humphries, 1947) and *Tropical Architecture in the Humid Zones* (Huntington, NY: Kreiger, 1956); Hannah le Roux, "The Networks of Tropical Architecture" The *Journal of Architecture* 8, no. 8 (Autumn 2003): 337-356.

72 By the mid-50s, the buildings discussed above were being referred to as MIT Solar Houses I, II, and III. House III was consumed by fire in 1955. Around Christmas of that year, while the student family that lived in the house was out of town, a fire started in the insulating panels near the water storage tank in the 'attic.' The fire department was called; when they arrived, they first attacked the solar collectors from which the smoke appeared to be emanating, thereby ending the experimental life of the M.I.T. Solar House. As Hottel was quick to note in his report on the incident, "Careful

With the evacuation of the political and economic logics of solar heating, *House IV* expressed, as did the AFASE competition indicated above , a proposal for the cultural logic of solar living. Here again, however, the potential of *House IV* as a reproducible example of a fuel-efficient suburban lifestyle foundered in the face of the industry mechanics of real estate development. In a 1945 letter to Cabot, Hottel was enthusiastic about the possibility of taking advantage of the expanding post-war market in single-family homes to produce

14; Lawrence Anderson, MIT Solar House IV, 1958, From Lawrence Anderson, MIT House IV, (MIT Department of Architecture, 1959). **below**; Anderson and his family cooking hotdogs on a solar stove, 1959. From Hottel Papers.





multiple iterations of solar experimentations. He wrote: "we propose actually to build a dwelling house, to use it for a short time as a laboratory, and then to dispose of it on the open market and proceed with designs based on lessons learned in construction of the first dwelling."[74] In an interview in 1984, he reflected on the later project in these terms:

> [at House IV] the contractor had installed a [heating] shaft with a crook in it. That had absolutely nothing to do with the solar system, it was just a defective air heater. But because it was a solar house, anything that went wrong would bring a home-owner response, "I don't know what's wrong with this. This is a solar house. Call Professor Hottel"... We woke up to the fact that any little thing that went wrong would require consulting and correction by a member of the M.I.T. faculty. The idea wouldn't work, there had to be a service organization in existence, and there weren't any for solar houses. After two years of testing, we finally sold solar house number four after ripping out all of its solar parts and refitting it with a conventional heating system. We had to give up on the idea of learning by building solar houses for the public.[75]

In fact they gave up altogether; House IV was the last venture of the Space Heating subcommittee.

In 1963 the Solar Energy Fund was reorganized. No longer under Hottel's direct purview, much of the budget was reallocated to support research in nuclear energy.[76] Also in 1963, Barnett—by this time director of the Resources and Natural Growth Division at Resources for the Future and representative of the organization's decisive conservative turn—published *Scarcity and Growth: The Economic of Natural Resource Availability*, a definitive expansion of his late 40s proposal that sought to transform the approach of environmental economists towards accommodating the needs of consumer expansion while attempting to mediate catastrophic damage to the environment and natural resources. Barnett's was again a proposal for a sustainable future reliant on accommodations between economy and ecology, rather than an environmentalist one. The global infrastructure of oil, of course, was by this time wholly instantiated.[77] Thus does Rachel Carson's 1963 *Silent Spring* appear to articulate a new consciousness of ecological interconnection at exactly the same time

examination of every element of the solar heating system showed no evidence that the latter could have contributed to the fire, and uncovered no weaknesses which should affect the design of the next house. Hoyt C. Hottel, "Report on A Fire in the 3rd M.I.T. Solar House, 450 Memorial Drive 12/23/55," box 27, Hottel Papers.

73 A pamphlet was produced upon completion of the house, describing its design and heating system. See Lawrence Anderson, et. al., *Solar House IV* (Cambridge, MA: M.I.T. Office of Publications, 1958).

74 Letter, Hottel to Cabot, July, 1945, box 18, Hottel Papers.

75 Bohning, "Hoyt C. Hottel: Transcripts of Interviews," 62.

76 Officially "broadening of the base" of the fund, according a documented discussion between Cabot and Compton right after the atom bombs dropped in August of 1945 that had been ignored until rediscovered after Cabot's death in 1962. Letter, Compton to Cabot, July 23, 1945, 1-2; Killian that the multivalent discourse on solar energy hits a wall, marking the death of an earlier environmentalism which, with its interdisciplinary attempt to articulate a worldview in which techno-cultural innovation could respond to changes in the resource condition, proposed the importance of new dreams in response to new political and material realities.

While the overdetermined decline of solar viability needs to be understood in the context of the technology and consumption flows that supported the importation of oil and its use for home heating, it can also be connected, through the architectural engagements of the Solar Energy Fund and its progeny, to the slow demise of modern architecture. If the modern solar house is integrated into the history of architecture without much difficulty, it nonetheless occurs with great consequence; in the current context of the geographic and epistemic changes wrought by climate change and other environmental catastrophes, narratives such as the one detailed here indicate that the historical forces seen to condition the developments of modern architecture need to be re-conceived. Shifting away from the culturally mediating role of modernism in relation to the potentials and pitfalls of industrialization in both its pre- and post-war manifestations, historical attention should instead focus on the 'environmentalization' of the architectural discourse across the long twentieth century. In the techno-cultural history of the modern solar house, the cultural logic of solar architecture was the last effort to formulate an argument of new ways of living; architectural form-making was relied on to express a distinctly different disposition towards energy production and consumption. The inadequacy of design and material experimentation is not an opportunity to re-iterate the political vacuity of architectural intentions; rather it is an opportunity to emphasize the cultural, technological and political constellations of architectural engagement as evidence of an environmentalist disposition, one that saw the objective pressures of resources scarcity as an opportunity for new forms of subjectivity.

to Hottel, September 13, 1945; Letter Killian to Cabot Dec. 23, 1953. Letter, Killian to LW Cabot, February 26, 1963; all in box 43, folder 22, M.I.T. Office of the President Records, Solar Energy Fund (AC 4), Institute Archives.

77 Both Barnett in 1963 and Amory Lovins in 1977 identify 1958 as the year that the perception of continuous oil availability took on global proportions and established what Lovins would call the "Hard Energy Path" of infrastructure intensive fuel extraction and provision. See Amory B. Lovins, *Soft Energy Paths: Towards a Durable Peace* (New York: Harper, 1977). Lovins' major project was to resist the reliance on nuclear energy as a way out of fuel crises. He persists in this project in his organization of The Rocky Mountain Institute, still active today. For Barnett, in addition to the texts cited above, see Harold J. Barnett, "The Changing Relation of Natural Resources to National Security," *Economic Geography* 34, no. 3 (July 1958), 189-201.