Innovative Office Building Structures and Enclosures: A Survey of Experts
INNOVATIVE OFFICE BUILDING STRUCTURES
AND ENCLOSURES:
A SURVEY OF EXPERTS

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November 1984
ABSTRACT

This report presents the results of a study undertaken to identify probable trends affecting the form/design, materials and construction technologies of future office buildings. A literature review was conducted that addressed emerging technologies for structural systems and exterior enclosures of office buildings. Issues identified in the review were used to develop questionnaires for surveying expert opinions about technological innovations. Experts estimated the availability and importance of various structural and enclosure innovations, and provided their perceptions of the benefits and constraints of up to 10 innovations of their choosing.

Keywords: Buildings; construction; design; enclosures; materials; structural engineering.
EXECUTIVE SUMMARY

This report describes the methodology employed and the results obtained from a study to identify probable trends affecting the form/design, materials and construction technologies of future office buildings. On the basis of a literature review, questionnaires were developed to elicit expert opinion on technological innovations related to structural systems and exterior enclosures. Experts estimated the availability and importance of various structural and enclosure innovations, and the benefits and constraints associated with selected innovations. Structural and enclosure innovations not included in the survey questionnaires, but considered by the experts to be of significance in assessing probable trends, were also identified.

A total of 131 innovations (48 structural and 83 enclosure) were addressed and 86 experts participated in the survey. The experts identified an additional 31 innovations, some of which are variations of those innovations contained in the questionnaires.

More than one third of the respondents believe that 35 of the 48 structural innovations identified in the questionnaires are available or will become available by 1985.

- Tubular structures and the reduction or accommodation of wind and seismic forces emerge as structural innovations of major importance. The use of lightweight, high-strength, reinforced concrete and the design of composite structures of steel and reinforced concrete construction are also viewed as important structural innovations. In the general area of industrialization/prefabrication, large scale prefabricated-prefinished structural elements, large scale facade elements, composite steel/prefab concrete structural systems, and innovative applications of post tensioning are considered to be of major importance. Each of these innovations is considered by a significant number of respondents to be available no later than 1985.

Structural innovations believed to be of major or moderate importance and requiring additional research and development over the next 5 to 10 years include: computer-aided construction; megaframes to provide vertical flexibility; y-shape box columns in seismic design; and structural damping augmented by means of damping friction at bolted connections.

Innovations considered to be of major importance to the design and construction of enclosures and currently available include: minimizing rainwater penetration by reducing the number of joints in exterior enclosures; prefab mass walls using precast wall components; passive methods such as improved building geometry to minimize heating, cooling and lighting; active sensor systems to automatically relate the interior environment to outside conditions and thus conserve operational energy; sun control using improved roof overhangs; improved prefabricated insulating decks; and the use of single-ply continuous roofing membranes.

Other enclosure innovations believed to be of major importance but requiring additional research and development before they can be considered available and dependable include thermal modeling in design and photovoltaic cells for conserving operational energy.

Benefits most commonly associated with the selected structural innovations were cost savings, enhanced structural integrity and improved design. The constraints most frequently mentioned were added costs and the need for specially trained personnel.
Benefits most commonly associated with the selected enclosure innovations were cost savings, enhanced structural integrity and enhanced energy conservation. The constraint most frequently mentioned was a reduction in design options.
ACKNOWLEDGMENTS

The authors would like to express gratitude to Erma Striner, the Project Monitor, Public Buildings Service, General Services Administration for her assistance, insights, and patience during the conduct of the project. John L. Gross, R. D. Marshall and Noel Raufaste provided critical reviews of the drafts. Finally, the authors wish to thank the staff of the CBT Word Processing Center.
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1. INTRODUCTION

1.1 BACKGROUND

Advances or changes in design and analysis methods, materials, and/or construction techniques can have a significant effect on building design and construction. The consequences of advances or changes in building technology can be pervasive and both favorable and unfavorable. In some cases, by the time they have been translated into plans for action or policy positions, the advances or changes may have little effect. Therefore, building operators and developers need information about potential developments in order to accommodate the long lead-time required for evaluation and implementation of programs or policy. The survey of technical experts reported herein was undertaken to help provide the needed information.

1.2 OBJECTIVES AND SCOPE OF THE STUDY

Under a memorandum of understanding with the General Services Administration (GSA), the National Bureau of Standards (NBS), Center for Building Technology (CBT), has undertaken a study to identify probable trends affecting the form/design, materials and construction technologies of future office buildings. The study focuses on trends specifically associated with building structural systems and enclosure (exterior wall and roof) systems. The results of the study will be used by the Public Buildings Service (PBS) of GSA as reference-information input to its building design programming, building design evaluation, and research planning processes.

The primary objectives of the study were:

1. To generate a list of categories for which there is evidence of current or near-term technological innovation;

2. To assess, using the opinions and judgement of experts, when these innovations might occur;

3. To determine what benefits might accrue from the technological innovations; and

4. To determine what constraints the innovations might operate within.
2 DESCRIPTION OF THE STUDY

2.1 METHODOLOGY

A literature review was conducted that addressed emerging technologies in the areas of materials, design and construction for structural systems and exterior enclosures of office buildings. New, changing, emerging and proposed innovations were addressed with emphasis given to proposed innovations that were considered likely to be achieved over the short term (5 to 15 years).

The literature review focused on archival sources but also included computer searches of bibliographic databases and discussions with peers. The review resulted in a compilation of technological innovations and associated issues. At the request of the GSA/PBS, the literature review was published and has been widely disseminated [1].

The issues identified in the review were used to develop questionnaires for exploring expert opinions about technological innovations. Two questionnaires were developed, suitable for self-administration. They covered structural innovations and exterior enclosure innovations, respectively. Appendix A contains both questionnaires. There were 14 categories of structural innovations covering 48 innovations and 28 categories of exterior enclosure innovations covering 83 innovations.

Respondents could add innovations to the list and these were subsequently evaluated to determine if they should be included in this study or not. Respondents were asked when, in their opinion, each innovation would probably occur in a sufficient number of projects to be treated as an available and dependable technology. The six response options were: already available and dependable; available and dependable by 1985; by 1990; by 1995; later than 1995; never. A 15-year future time limit was chosen because, as Schön [2] has argued, the probability of a correct forecast, other factors being equal, is inversely related to the time span of the forecast.

Respondents were also asked to evaluate each innovation for its importance, the evaluation varying from "it is of minor importance" to "it is of the greatest importance" in terms of the benefits the innovation would confer, its impact and its ability to solve pressing problems.

Last, each respondent was asked to select up to ten innovations rated as most important and discuss for each the likely major benefits resulting from its use and the likely major constraints to early or widespread acceptance. The respondents were mailed the questionnaires and a return envelope along with instructions for completing the questionnaires.

Approximately two months after the initial mailing (in July, 1983), respondents who had not returned a questionnaire were sent letters reminding them of their agreeing to participate in the study and asking them again to complete the questionnaires they had been sent.

Approximately three months after the letter (in October, 1983), all experts whose questionnaires had still not been returned were phoned and were asked to complete
the questionnaires or, if they wished, ask another expert to complete the questionnaires for them.

2.2 PARTICIPANTS

Over 200 architectural engineers, civil engineers and structural engineers in private architectural/engineering (A/E) firms and universities were identified as potential respondents. The individuals selected were heads of structural engineering departments in private firms having billings of $1 million or more during 1981, heads of civil engineering programs at universities that also have architectural programs, or heads of university architectural engineering programs.

Individuals from large firms were selected as potential respondents because it was assumed that the large firms offered managers greater opportunities for obtaining extensive and diversified experiences with state-of-the-art technologies. Civil engineering program heads at universities having architectural programs were selected because it was assumed that there would be a greater likelihood of structural engineering courses related to buildings and a potential interest in buildings within those civil engineering programs. Other individuals identified as leading innovators in architecture and engineering by the NBS, GSA and BOSTI staffs were included.

The individuals selected were mailed a letter describing the study and requesting their participation. There were 86 individuals who responded with 25 agreeing to complete the structural innovations questionnaire, 6 agreeing to complete the enclosure system innovations questionnaire, and 55 agreeing to complete both questionnaires.
3. EXPERT RESPONSES

3.1 NUMBER OF RESPONDENTS

The response rate was 51 percent. This is considered to be good for a mail survey but less than was expected given the expressed willingness of the experts to participate. There were 14 individuals who responded to the structural innovations questionnaires, 3 individuals who responded to the enclosure innovations questionnaires, and 27 individuals who responded to both questionnaires.

3.2 ANALYSES OF RESPONSES

The responses to the questionnaires are presented in tables A1 through A9 of Appendix B. Tables A1 and A2 present results of respondents' estimates of the availability and importance of structural innovations. Estimates of the availability and importance of enclosure innovations are presented in tables A3 and A4.

Tables A5 and A6 of Appendix B present results of respondents' opinions regarding the benefits and constraints associated with structural innovations. Corresponding results for enclosure innovations are presented in tables A7 and A8 of Appendix B. Only those innovations to which at least five experts responded with benefits are included. Because constraints tended to be mentioned less frequently than benefits and in order to maintain some symmetry to the analysis, "constraints" results were examined only for those innovations included in the "benefits" group. As a result of this decision rule, there are some innovations in the "constraints" group for which fewer than five respondents gave constraints. Coding categories and definitions of these categories used to assemble tables A5 through A8 can be found in the coding manual which is included as Appendix C.

In addition to those innovations listed in the questionnaires, respondents were encouraged to add their own innovations. None of the added innovations was mentioned by sufficient numbers of respondents to justify including them in any of the analyses of responses. These added innovations are listed in table A9 of Appendix B.

3.2.1 Order of Completion

Respondents' estimates of availability and importance (tables A1 through A4, Appendix B) were examined to determine whether or not the order of questionnaire completion influenced the results. No statistical tests were carried out, but cursory inspection of responses indicated no dramatic effect of order of completion.

3.2.2 Innovations - Selection for Discussion

A comparison was made of the importance assigned by respondents who did versus those who did not choose a specific innovation for discussion of its benefits and constraints. Since the importance of an innovation was a condition for its selection for discussion (see questionnaire), this comparison served as a validity check; that is, a check on whether or not the instruction was being followed.
The comparison was limited to selected structural innovations because more respondents completed the structure questionnaires. The following structural innovations were used in the validity check.

- Frame-truss combination; Outrigger truss; "Tie-down" truss
- Tubular structures
- Aerodynamically stable building forms
- Lightweight, high-strength reinforced concrete
- Lightweight alloys

All ratings of the importance of these five structural innovations were merged for all of the respondents who selected one or more of them for discussion. Thus, the sample was boosted to 46 ratings of the importance of these five innovations, each rating representing a case in which the specific innovation had been selected for the discussion of benefits and constraints.

To create a control group, respondents who did not choose any of the five structural innovations listed above for discussion of benefits and constraints were selected. There were 19 of these respondents. Table 1 summarizes how many ratings were assigned, by innovation, to each level on the importance scale for those who did select an innovation for discussion (Group 1) and for those who did not select any of the five (Group 2).

It can be seen from Table 1 that almost 90 percent of the ratings assigned by Group 1 fall into the two highest positions on the importance scale. This compares with approximately 40 percent of the ratings assigned by Group 2. Therefore, it appears that the respondents' discussion of benefits and constraints is in large part directed at innovations that are considered to be of major importance.
4. DISCUSSION OF RESULTS

In order to simplify interpretation of the survey results with regard to availability and importance, the data presented in tables A1 through A4 of Appendix B are summarized in tables 2 and 3 of the text. The procedure used was to adopt three classes of availability as follows:

- Available by 1985
- Available within 5 to 10 years
- Available over the long-term or never.

Importance was classified as being major, moderate or minor with these classes encompassing the following segments of an importance scale contained in the questionnaires:

- Major - 9 to 8
- Moderate - 7 to 5
- Minor - 4 to 0

The percentage of responses falling within each of the classes was then determined and, for clarity of presentation, only the most significant percentages for each innovation have been listed in tables 2 (structural) and 3 (enclosure). For those cases in which two classes are of equal or approximately equal significance, both percentages have been tabulated.

4.1 AVAILABILITY AND IMPORTANCE OF STRUCTURAL INNOVATIONS

The availability and importance of structural innovations are summarized in table 2. With regard to availability, more than one third (and in most cases substantially more than one third) of the respondents believe that 35 of the 48 structural innovations identified in the questionnaires are available or will become available by 1985. Only two innovations (flexible sliding foundations and plastics for mass reduction and increased ductility) are considered by a significant number of respondents to become available only over the long term or to never become available.

With regard to importance of structural innovations, it is apparent from table 2 that those innovations considered to be of greater importance tend to be considered as available by 1985. Structural innovations that are considered by more than half of the respondents to be of major importance include the following:

- Tubular structures
- Lightweight, high-strength reinforced concrete
- Steel and reinforced concrete construction
- Post tensioning
- Computer-aided construction
Of these five innovations, only computer-aided construction is seen as becoming available and dependable at some time beyond 1985.

**Structural innovations that are considered by a significant number (but less than half) of the respondents to be of major importance are:**

- Hollow tubular buildings
- Aerodynamically stable building forms
- For very large bldgs, ensure appropriate dimensions or seismic subdiv.
- Ensure vertical continuity or seismic separation at setbacks
- Large scale prefabricated-prefinished structural elements
- Large scale facade elements
- Industrialized systems
- Composite steel/precast concrete structural systems

Each of these innovations is considered by a significant percentage of the respondents to be available now or to become available by 1985.

**Structural innovations that are considered by at least half of the respondents to be of moderate importance include the following:**

- Frame-truss combination; Outrigger truss; "Tie-down" truss
- Megaframes
- Exterior shafts
- Y-shape box columns
- Damping friction at bolted connections
- Reinforced earth
- Steel plate cladding bonded to concrete members
- Fabric structures (Re relocatable buildings)
- Tension structures
- Interstitial space
- Exterior shafts, ducts
- Prefab space modules
- Fabric structures (Re prefabrication/industrialization)

Of these 13 structural innovations 10 are considered to be available now or will become available by 1985. Three innovations (megaframes, y-shape box columns, and damping friction at bolted connections) are expected to become available within 5 to 10 years.

**4.2 AVAILABILITY AND IMPORTANCE OF ENCLOSURE INNOVATIONS**

The availability and importance of enclosure innovations are summarized in table 3. As is the case for structural innovations, a high percentage (57 out of 83 or 69 percent) of the enclosure innovations are considered by a significant number of respondents to be available now or will become available by 1985. Only one enclosure innovation, super-envelope over a group of buildings, is considered likely to become available over the long term or will never become available. This view is shared by 68 percent of the respondents.
With regard to importance of enclosure innovations, 9 are considered by more than half of the respondents to be of major importance. These innovations are as follows:

- Water tighten joints
- Precast concrete wall component
- Sandwich panel systems
- Building geometry
- Sensors to automatically relate interior envir. to outside cond.
- Improve overhangs
- Increase air tightness
- Improved prefabricated insulating decks
- Single-ply continuous membranes

More than half of the respondents share the opinion that each of these innovations will be available and dependable no later than 1985.

Enclosure innovations that are considered by a significant number (but less than half) of the respondents to be of major importance are:

- Thermal modeling in design
- Wind resistant design
- Reduce joints (Minimize rainwater penetration)
- External insulation
- Integrated wall panel construction systems
- Absorbers/heat pump
- Solar collectors
- Photovoltaic cells
- Reduce total length of joints
- Improve glazing area (double panes w/krypton gas, heated mirror film)
- Operable windows

With the exception of thermal modeling in design and photovoltaic cells, all of these innovations are considered likely to become available and reliable no later than 1985. A 5 to 10 year development period is considered likely for these two innovations. As with structural innovations, enclosure innovations considered to be of greater importance tend to be considered as available no later than 1985.

Enclosure innovations that are considered by at least two thirds of the respondents to be of moderate importance include the following:

- Design using solar envelopes
- Interchangeable components and access to building's exterior
- Surface coated porous fire clay
- Insulating ceramic tiles
- Surface impregnated cellular concrete
- Introduce dynamic insulation devices ("Beadwall," blinds, roll-up shades)
- Increase thermal storage capacity in edge zones (phase-change panels)
In the opinion of a significant number of respondents (more than one third), each of these enclosure innovations will require 5 to 10 years to become available and dependable.

4.3 BENEFITS AND CONSTRAINTS OF SELECTED INNOVATIONS

Structural innovations in the following categories met the criteria for analysis of benefits and constraints (see section 3.2 and tables A5 and A6 of Appendix B).

STIFFNESS IN HIGHRISE BUILDINGS
WIND RESISTANT DESIGN
SEISMIC DESIGN
MATERIALS DEVELOPMENT
FOUNDATIONS
COMPOSITE STRUCTURE
FIRE PROTECTION
MASS REDUCTION AND INCREASED DUCTILITY
PREFABRICATION/INDUSTRIALIZATION

The benefits most commonly associated with the selected innovations were cost savings, enhanced structural integrity and improved design. The constraints most frequently mentioned were added costs and the need for specially trained personnel. The major area of discussion and point of disagreement concerning the structural innovations was whether or not the benefit of cost savings was sufficient to offset the constraint of added costs.

Enclosure innovations in the following categories met the criteria for analysis of benefits and constraints (see tables A7 and A8 of Appendix B).

SOPHISTICATED DESIGN/EVALUATION PROCEDURES
REDUCE HIGH-WIND EFFECTS
MINIMIZE RAINWATER PENETRATION THROUGH JOINTS
USE OF COMPOSITE MATERIALS
USE OF PREFAB MASS WALLS
USE OF MINIMUM MASS SKIN COMPONENTS
PASSIVE METHODS FOR MINIMIZING HEATING/COOLING/LIGHTING
CONSERVE OPERATIONAL ENERGY BY ACTIVE SYSTEMS

The benefits most commonly associated with the selected innovations were cost savings, enhanced structural integrity and enhanced energy conservation. The constraint most frequently mentioned was constraint of design options.

In general, cost savings was most frequently mentioned as the benefit to be derived from the selected structural and enclosure innovations. However, there was no commonly shared constraint between the two types of innovations.
5. IMPLICATIONS FOR GSA/PBS

This survey of experts has identified a number of structural and enclosure innovations that are considered to be of major importance in office building construction. Most of these innovations are considered to be available and reliable now (at time of survey, 1983) or are considered likely to become so by 1985. The survey also identified innovations not included in the questionnaires, but that are believed by some of the experts to be of importance in current construction or to merit further research and development.

The following sections summarize survey findings that may be helpful to GSA/PBS in reviewing its current practice and strategy for the planning and construction of office buildings. Included are innovations that are viewed by the experts to be of major importance and to be available and dependable at the present time, innovations that will require additional research and development, and selected innovations that were identified but not evaluated during this survey. These innovations are consolidated in table 4.

5.1 STRUCTURAL INNOVATIONS

With regard to primary structural systems, tubular structures and the reduction or accommodation of wind and seismic forces emerge as innovations of major importance. The use of lightweight, high-strength, reinforced concrete and the design of composite structures of steel and reinforced concrete construction are also seen as important structural innovations. Important innovations in the general area of industrialization/prefabrication include: large scale prefabricated-prefinished structural elements; large scale facade elements; composite steel/prefab concrete structural systems; and post tensioning. All of these innovations are viewed as being available and dependable no later than 1985.

Structural innovations considered to be of major or moderate importance and requiring additional research and development over the next 5 to 10 years include: computer-aided construction; megaframes to provide for vertical flexibility; y-shape box columns in seismic design; and structural damping augmented by means of damping friction at bolted connections.

Additional structural innovations identified by the respondents during the survey include: bundled tube structures; concrete admixtures to eliminate shrinkage; seismic base isolation using lead-rubber bearings; and preassembled floor segments.

5.2 ENCLOSURE INNOVATIONS

Innovations considered to be of major importance to the design and construction of enclosures include: minimizing rainwater penetration by reducing the number of joints in the enclosure; prefab mass walls using precast wall components; passive methods such as improved building geometry to minimize heating, cooling and lighting; active sensor systems to automatically relate the interior environment to outside conditions and thus conserve operational energy; sun control using improved roof overhangs; control of air infiltration/exfiltration through
increased air tightness; improved prefabricated insulating decks; and the use of single-ply continuous roofing membranes. All of these innovations are considered to become available and dependable no later than 1985.

Other enclosure innovations believed to be of major importance but requiring additional research and development before they can be considered available and dependable include: thermal modeling in design; and photovoltaic cells for conserving operational energy.

Selected enclosure innovations identified by the survey but not include in the survey questionnaires are inverted roof membrane assemblies; completely prefabricated insulating deck with roof membrane and built-in vapor barrier; and reduced solar load with steep sloping or folded plate self-shading roofs. As with structural innovations, the enclosure innovations identified by the respondents during the survey may more closely match the current interests and concerns of GSA/PBS.
6. REFERENCES


Table 1. Number of Ratings Assigned to Each Scale Position for Each of Five Structural Innovations for Two Respondent Groups

<table>
<thead>
<tr>
<th>IMPORTANCE SCALE POSITIONS</th>
<th>INNOVATION 1</th>
<th>GROUP 1</th>
<th>GROUP 2</th>
<th>TOTAL</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
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<tr>
<td>9</td>
<td>2</td>
<td>11</td>
<td>7</td>
<td>32</td>
</tr>
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</table>

Note: 1a = Frame-truss combination; Outrigger truss; "Tie-down" truss

1d = Tubular structures

3a = Aerodynamically stable building forms

6a = Lightweight, high-strength reinforced concrete

12a = Lightweight alloys
Table 2. Summary of Availability and Importance of Structural Innovations

<table>
<thead>
<tr>
<th>INNOVATIONS</th>
<th>AVAILABILITY (%)</th>
<th>IMPORTANCE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>By 1985</td>
<td>5-10 years</td>
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<tr>
<td>1 STIFFNESS IN HIGHRISE BUILDINGS</td>
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<td></td>
</tr>
<tr>
<td>a Frame-truss combination; Outrigger truss; &quot;Tie-down&quot; truss</td>
<td>76</td>
<td>59</td>
</tr>
<tr>
<td>b Exterior steel plate shear walls</td>
<td>46</td>
<td>51</td>
</tr>
<tr>
<td>c Inclined or pyramid-shaped frame</td>
<td>67</td>
<td>46</td>
</tr>
<tr>
<td>d Tubular structures</td>
<td>90</td>
<td>54</td>
</tr>
<tr>
<td>2 VERTICAL FLEXIBILITY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a Megaframes</td>
<td>42</td>
<td>53</td>
</tr>
<tr>
<td>b Hollow tubular buildings</td>
<td>50</td>
<td>37</td>
</tr>
<tr>
<td>c Exterior shafts</td>
<td>53</td>
<td>51</td>
</tr>
<tr>
<td>d Vertically curved or folded plate walls as support</td>
<td>40</td>
<td>51</td>
</tr>
<tr>
<td>3 WIND RESISTANT DESIGN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a Aerodynamically stable building forms</td>
<td>44</td>
<td>49</td>
</tr>
<tr>
<td>b Drag reduction</td>
<td>38</td>
<td>49</td>
</tr>
<tr>
<td>4 SEISMIC DESIGN</td>
<td></td>
<td></td>
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<tr>
<td>a Y-shape box columns</td>
<td>50</td>
<td>56</td>
</tr>
<tr>
<td>b Eliminate &quot;soft storey&quot;</td>
<td>63</td>
<td>46</td>
</tr>
<tr>
<td>c Shear walls graduated by height</td>
<td>79</td>
<td>46</td>
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Table 2. Summary of Availability and Importance of Structural Innovations (Cont.)

<table>
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<th>AVAILABILITY (%)</th>
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<th>IMPORTANCE (%)</th>
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<tr>
<td></td>
<td>By 1985</td>
<td>5-10 years</td>
<td>Long-term or never</td>
</tr>
<tr>
<td>d For very large bldgs, ensure appropriate dimensions or seismic subdiv.</td>
<td>69</td>
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<tr>
<td>e Ensure vertical continuity or seismic separation at setbacks</td>
<td>58</td>
<td>44</td>
<td>44</td>
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<tr>
<td>f Eccentric braced frames</td>
<td>66</td>
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<tr>
<td>g Flexible sliding foundation</td>
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<td>5 STRUCTURAL DAMPING</td>
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<tr>
<td>a Active damping</td>
<td>41</td>
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<tr>
<td>b Visco-elastic damping</td>
<td>49</td>
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<td>c Damping friction at bolted connections</td>
<td>39</td>
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<td>51</td>
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<td>6 MATERIAL DEVELOPMENT</td>
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</tr>
<tr>
<td>a Light-weight, high-strength, reinforced concrete</td>
<td>55</td>
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<td>73</td>
</tr>
<tr>
<td>7 FOUNDATIONS</td>
<td></td>
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<tr>
<td>a Mixed-in-place stabilizers</td>
<td>60</td>
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<tr>
<td>b Preconsolidation</td>
<td>84</td>
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<tr>
<td>c Reinforced earth</td>
<td>64</td>
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<td>8 COMPOSITE STRUCTURE</td>
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<tr>
<td>a concrete exterior, steel interior frame</td>
<td>82</td>
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<tr>
<td>b Steel plate cladding bonded to concrete members</td>
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Table 2. Summary of Availability and Importance of Structural Innovations (Cont.)

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<td>5-10 years</td>
</tr>
<tr>
<td>c Steel and reinforced concrete construction</td>
<td>95</td>
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<tr>
<td>9 EXTERIOR FINISH</td>
<td></td>
<td></td>
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<tr>
<td>a Controlled rust steel or stainless steel</td>
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<tr>
<td>10 FIRE PROTECTION</td>
<td></td>
<td></td>
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<tr>
<td>a Water cooled structural membranes</td>
<td>45</td>
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<tr>
<td>b Fire resisting paint</td>
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<td></td>
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<tr>
<td>11 RELOCATABLE BUILDINGS</td>
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<tr>
<td>a Unit construction or modular space frame</td>
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<tr>
<td>b Plastic &quot;umbrella&quot;</td>
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<td></td>
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<tr>
<td>c Suspension cable structure</td>
<td>69</td>
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<tr>
<td>d Fabric structure</td>
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<tr>
<td>12 MASS REDUCTION AND INCREASED DUCTILITY</td>
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<tr>
<td>a Lightweight alloys</td>
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<td>b Plastics</td>
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<tr>
<td>c Tension structures</td>
<td>58</td>
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<tr>
<td>13 FLEXIBLE SERVICES</td>
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<tr>
<td>a Interstitial space</td>
<td>74</td>
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<tr>
<td>b Exterior shafts, ducts</td>
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Table 2. Summary of Availability and Importance of Structural Innovations (Cont.)

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<td>14 PREFABRICATION/INDUSTRIALIZATION</td>
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<tr>
<td>a Large scale prefabricated-prefinished structural elements</td>
<td>54</td>
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<td>b Large scale facade elements</td>
<td>76</td>
<td></td>
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<tr>
<td>c Industrialized systems</td>
<td>72</td>
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<tr>
<td>d Prefab space modules</td>
<td>62</td>
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<tr>
<td>e Post tensioning</td>
<td>93</td>
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<tr>
<td>f Composite steel/precast concrete structural systems</td>
<td>83</td>
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<tr>
<td>g Robotics</td>
<td>53</td>
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<tr>
<td>h Computer-aided construction</td>
<td>46</td>
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<tr>
<td>i Fabric structures</td>
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Table 3. Summary of Availability and Importance of Enclosure Innovations

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<tr>
<td>1 INTER-BUILDING CIRCULATION AND CLIMATIC BUFFER ZONES</td>
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<tr>
<td>a Pedestrian bridges (skyways) and clip-on corridors</td>
<td>82</td>
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<tr>
<td>b Enclosing space between buildings</td>
<td>68</td>
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</tr>
<tr>
<td>c Solaria (designed in or clip-on)</td>
<td>50</td>
<td></td>
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<tr>
<td>d Super-envelope over a group of buildings</td>
<td>68</td>
<td></td>
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<tr>
<td>2 NEW MATERIALS WHICH ALTER ENCLOSURE FORMS</td>
<td></td>
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<tr>
<td>a Modern &quot;permanent&quot; fabric structures (cable restraint, air support, etc.)</td>
<td>52</td>
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</tr>
<tr>
<td>3 SOPHISTICATED DESIGN/EVALUATION PROCEDURES</td>
<td></td>
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<tr>
<td>a Computer generated facades</td>
<td>44</td>
<td>44</td>
</tr>
<tr>
<td>b Design using solar envelopes</td>
<td>48</td>
<td></td>
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<tr>
<td>c Thermographic cameras to detect leaks</td>
<td>59</td>
<td></td>
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<tr>
<td>d Thermal modeling in design</td>
<td>54</td>
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### Table 3. Summary of Availability and Importance of Enclosure Innovations (Cont.)

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<tr>
<td>REDUCE HIGH-WIND EFFECTS</td>
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<td>Wind resistant design</td>
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<tr>
<td>&quot;Roughen&quot; perimeter surface with protrusions, setbacks, etc.</td>
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<tr>
<td>MINIMIZE RAINWATER PENETRATION THROUGH JOINTS</td>
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<tr>
<td>Reduce joints</td>
<td>63</td>
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<tr>
<td>Water tighten joints</td>
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<td></td>
</tr>
<tr>
<td>Use rainscreen/decompression chamber/drained joint</td>
<td>52</td>
<td></td>
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<tr>
<td>FACILITATE FUTURE FACADE CHANGES</td>
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<tr>
<td>Interchangeable components and access to building's exterior</td>
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<tr>
<td>USE OF HOMOGENOUS, IN-ORGANIC CELLULAR MATERIALS</td>
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<tr>
<td>Cellular or foamed glass</td>
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<tr>
<td>Cellular or aerated concrete</td>
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<td></td>
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<tr>
<td>Foamed ceramic bricks</td>
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<tr>
<td>USE OF THERMAL INSULATION MATERIALS FOR EXTREME OUTSIDE OF EXTERIOR WALL</td>
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<td>External insulation</td>
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Table 3. Summary of Availability and Importance of Enclosure Innovations (Cont.)

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<tr>
<td></td>
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<td>Major</td>
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<tr>
<td>b Surface coated porous fire clay</td>
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<tr>
<td>c Insulating ceramic tiles</td>
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<td></td>
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<tr>
<td>9 USE OF COMPOSITE MATERIALS</td>
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<tr>
<td>a Surface impregnated cellular concrete</td>
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<tr>
<td>b Glass fiber reinforced concrete cladding</td>
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<td>52</td>
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<tr>
<td>c Integrated wall panel construction systems</td>
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<tr>
<td>10 USE OF PREFAB MASS WALLS</td>
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<tr>
<td>a Prefab brick wall component</td>
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<td>b Precast concrete wall component</td>
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<td>11 USE OF MINIMUM MASS SKIN COMPONENTS</td>
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<tr>
<td>a Sandwich panel systems</td>
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<tr>
<td>b Ultra-thin sandwich material</td>
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<td>58</td>
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<tr>
<td>c Tinted, heat-absorbing, reflective glass wall</td>
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<td></td>
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<tr>
<td>d Firestop glazing</td>
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Table 3. Summary of Availability and Importance of Enclosure Innovations (Cont.)

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<tr>
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<tr>
<td>12 USE OF BUTT JOINT GLASS PANES (for continuous fenestration)</td>
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<tr>
<td>a Silicone glazing sealants</td>
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<td>13 CONSERVE OPERATIONAL ENERGY BY PASSIVE METHODS FOR MINIMIZING HEAT'G/COOL'G/LIGHT'G</td>
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<tr>
<td>a Building geometry</td>
<td>79</td>
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<tr>
<td>b Glazed area in wall</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td>c Heat loss through joints</td>
<td>67</td>
<td></td>
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<tr>
<td>d Operable windows</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>e Air-to-air heat exchangers</td>
<td>67</td>
<td></td>
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<tr>
<td>f Thermal mass for natural cooling</td>
<td>56</td>
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<tr>
<td>g Trombe walls, solaria, atria, 2nd envelope</td>
<td>52</td>
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<tr>
<td>14 CONSERVE OPERATIONAL ENERGY BY ACTIVE SYSTEMS</td>
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<tr>
<td>a Absorbers/heat pump</td>
<td>81</td>
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<tr>
<td>b Solar collectors</td>
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<tr>
<td>c Photovoltaic cells</td>
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<tr>
<td>d Sensors to automatically relate interior envir. to outside cond. for optimal energy management</td>
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Table 3. Summary of Availability and Importance of Enclosure Innovations (Cont.)

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<tr>
<td>15 SUN CONTROL WITH EXTERIOR SHADING DEVICES</td>
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</tr>
<tr>
<td>a Improve overhangs</td>
<td>83</td>
<td></td>
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<tr>
<td>b Use of vines and plants</td>
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</tr>
<tr>
<td>c Use lightweight sun screen</td>
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<tr>
<td>d Operable exterior venetian blinds</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>e Adjustable exterior louvers</td>
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<td></td>
</tr>
<tr>
<td>f Fabric shades, awnings</td>
<td>93</td>
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<tr>
<td>g Solar shutters (panels or rolling)</td>
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<td>46</td>
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<td>16 SUN CONTROL WITH INTERIOR SHADING DEVICE</td>
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<tr>
<td>a Improved curtain material</td>
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<td>b Rollshades (tightly sealing)</td>
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<tr>
<td>c Vinyl-coated fabric (semi-transparent or translucent)</td>
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<tr>
<td>d Reflective synthetic films</td>
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<tr>
<td>e Adjustable louvers, blinds</td>
<td>93</td>
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</tr>
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<td>INNOVATIONS</td>
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<tr>
<td>17 SUN CONTROL IN WINDOW PLANE</td>
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<tr>
<td>a Venetian blinds or shades between glass</td>
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<td>b Coated, absorbing, tinted glass</td>
<td>85</td>
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<td>c Spectrally selective glass</td>
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<td>d Optical shutter of thermally &quot;opacifiable&quot; glass</td>
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<td>e Photochromic glass</td>
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<tr>
<td>f Solar control films with adhesive backing</td>
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<tr>
<td>g Tilted window</td>
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<td>18 REFLECTION DEVICES TO BEAM DAYLIGHT INTO WORK ENVIRONMENT</td>
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<td>a Light shelves</td>
<td>58</td>
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<tr>
<td>b Paired reflectors with tilted window</td>
<td>43</td>
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<td>c Adjustable horizontal blinds</td>
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<td>19 CONTROL AIR INFILTRATION/EXFILTRATION</td>
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<tr>
<td>a Increase air tightness</td>
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<tr>
<td>b Reduce total length of joints</td>
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<td>INNOVATIONS</td>
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<td>-------------</td>
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<tr>
<td></td>
<td>By 1985</td>
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<tr>
<td>20 IMPROVE INSULATION VALUE OF WINDOWS</td>
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<tr>
<td>a Two parallel identical windows</td>
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<td></td>
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<td>b Improve frame (thermal breaks, rigid vinyl)</td>
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<tr>
<td>c Improv glazing area (double panes w/Krypton gas, heated mirror film)</td>
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<tr>
<td>d Introduce dynamic insulation devices (&quot;Beadwall&quot;, blinds, roll-up shades)</td>
<td>56</td>
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<tr>
<td>21 NATURAL VENTILATION</td>
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<tr>
<td>a Operable windows</td>
<td>93</td>
<td></td>
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<tr>
<td>b Ventilation through window frame</td>
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<tr>
<td>22 COUNTERACT UNCOMFORTABLE MEAN RADIANT TEMPERATURE (near window)</td>
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<tr>
<td>a Increase thermal storage capacity in edge zones.</td>
<td>67</td>
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</tr>
<tr>
<td>b Radiant floor or radiant ceiling</td>
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<tr>
<td>23 WINDOWS AS COMPREHENSIVE ENVIRONMENT MODIFIERS</td>
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<tr>
<td>a Reversible window with blinds on one side</td>
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### Table 3. Summary of Availability and Importance of Enclosure Innovations (Cont.)

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<td>By 1985</td>
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<tr>
<td>24 IMPROVED PREFABRICATED INSULATING DECKS</td>
<td>52</td>
<td>55</td>
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<td>25 CONTINUOUS ELASTIC ROOFING MEMBRANES</td>
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<tr>
<td>a Single-ply continuous membranes</td>
<td>76</td>
<td>66</td>
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<tr>
<td>26 REDUCTION OF THERMAL SHOCK ON ROOF MEMBRANE</td>
<td></td>
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<tr>
<td>a Through earth covering and planting</td>
<td>59</td>
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<td>27 UTILIZE ROOF AS ENERGY PLANT</td>
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<tr>
<td>a Self-tracking solar concentrators</td>
<td>56</td>
<td>62</td>
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<tr>
<td>b Wind generators, etc.</td>
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<td>55</td>
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<tr>
<td>28 REDUCED SOLAR LOAD ON ROOF</td>
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</tr>
<tr>
<td>a High parapets; roof-mounted shading devices</td>
<td>52</td>
<td>35</td>
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<td>Structural Innovations</td>
<td>Enclosure Innovations</td>
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</tr>
<tr>
<td>○ Tubular structures</td>
<td>○ Minimizing rainwater penetration by reducing the number of joints in the enclosure</td>
<td></td>
</tr>
<tr>
<td>○ Reduction or accommodation of wind and seismic forces</td>
<td>○ Prefab mass walls using precast wall components</td>
<td></td>
</tr>
<tr>
<td>○ Use of lightweight, high-strength, reinforced concrete</td>
<td>○ Passive methods such as improved building geometry to minimize heating, cooling</td>
<td></td>
</tr>
<tr>
<td>○ Design of composite structures of steel and reinforced concrete construction</td>
<td>and lighting</td>
<td></td>
</tr>
<tr>
<td>○ Large scale prefabricated-prefinished structural elements</td>
<td>○ Active sensor systems to automatically relate the interior environment to outside</td>
<td></td>
</tr>
<tr>
<td>○ Large scale facade elements</td>
<td>conditions and thus conserve operational energy</td>
<td></td>
</tr>
<tr>
<td>○ Composite steel/precast concrete structural systems</td>
<td>○ Sun control using improved roof overhangs</td>
<td></td>
</tr>
<tr>
<td>○ Post tensioning</td>
<td>○ Control of air infiltration/exfiltration through increased air tightness</td>
<td></td>
</tr>
<tr>
<td></td>
<td>○ Improved prefabricated insulating decks</td>
<td></td>
</tr>
<tr>
<td></td>
<td>○ Use of single-ply continuous roofing membranes</td>
<td></td>
</tr>
</tbody>
</table>

Innovations Requiring Additional Research and Development Over Next 5 to 10 Years

○ Computer-aided construction
○ Megaframes to provide for vertical flexibility
○ Y-shape box columns in seismic design
○ Structural damping augmented by means of damping friction at bolted connections
○ Thermal modeling in design
○ Photovoltaic cells for conserving operational energy

Selected Innovations Identified by Survey but not Included in Survey Questionnaires

○ Bundled tube structures
○ Concrete admixtures to eliminate shrinkage
○ Seismic base isolation using lead-rubber bearings
○ Preassembled floor segments
○ Inverted roof membrane assemblies
○ Completely prefabricated insulating deck with roof membrane and built-in vapor barrier
○ Reduced solar load with steep sloping or folded plate self-shading roofs
APPENDIX A. Questionnaires
AN EXPLORATION OF EXPECTED INNOVATIONS IN STRUCTURAL SYSTEMS OF OFFICE BUILDINGS

BACKGROUND:
Innovations in building technologies (in such areas as materials, development of sub-systems, building design, and construction methods) become widely available in the marketplace if they meet some or all of the following criteria:

- They provide higher levels of performance
- They permit uses or activities not now available or not now widespread
- They provide economies in first costs and/or in operating costs
- They satisfy new needs in the marketplace or regulatory requirements

We wish to explore emerging innovations in structural systems in office buildings and to assess when they might occur, what their benefits might be and what constraints they operate within.

The following is a list of categories for which there is some evidence of current or near-term technological innovation related to these systems:

CATEGORIES

- Stiffness in Highrise Buildings
- Vertical Flexibility (permitting floor height modification after a period of use)
- Wind Resistant Design
- Seismic Design
- Structural Damping (of ultra-high buildings)
- Material Development (where soils are weak or materials unavailable)
- Foundations
- Composite Structure
- Exterior Finish (for exposed steel which corrodes)
- Fire Protection (for exposed steel structural elements)
- Demountability (capacity to relocate buildings)
- Mass Reduction and Increased Ductility
- Services (providing for long-term flexibility in services)
- Prefabrication and Industrialization

A-2
Within each of these categories there are some particular types of innovations which have been reported in the technical journals. Some of these are listed below:

<table>
<thead>
<tr>
<th>CATEGORIES</th>
<th>INNOVATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Stiffness in Highrise Buildings</td>
<td>1a. Frame-truss combination; Outrigger truss;</td>
</tr>
<tr>
<td></td>
<td>Tying shear truss to exterior columns with belt trusses (&quot;tie-down&quot; truss)</td>
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<tr>
<td></td>
<td>1b. Exterior steel plate shear walls</td>
</tr>
<tr>
<td></td>
<td>1c. Inclined or pyramid-shaped frame</td>
</tr>
<tr>
<td></td>
<td>1d. Tubular structures</td>
</tr>
<tr>
<td>2. Vertical Flexibility</td>
<td>2a. Megaframes (supporting &quot;blocks&quot; of floors)</td>
</tr>
<tr>
<td>(permitting floor height modification</td>
<td>2b. Hollow tubular buildings</td>
</tr>
<tr>
<td>after a period of use)</td>
<td>2c. Exterior shafts</td>
</tr>
<tr>
<td></td>
<td>2d. Vertically curved or folded plate walls as supports</td>
</tr>
<tr>
<td>3. Wind Resistant Design</td>
<td>3a. Aerodynamically stable building forms</td>
</tr>
<tr>
<td></td>
<td>3b. Drag reduction (discharge air to leeward of building)</td>
</tr>
<tr>
<td>4. Seismic Design</td>
<td>4a. Y-shape box columns (in welded moment-resisting rigid steel frames, the use of welded Y-shaped box columns welded to girders.)</td>
</tr>
<tr>
<td></td>
<td>4b. Eliminate &quot;soft storey&quot; through: Widen base; add columns; add bracing;</td>
</tr>
<tr>
<td></td>
<td>energy dissipation</td>
</tr>
<tr>
<td></td>
<td>4c. Shear walls graduated by height</td>
</tr>
<tr>
<td></td>
<td>4d. For very large buildings, ensure appropriate dimensions, or make seismic</td>
</tr>
<tr>
<td></td>
<td>subdivisions</td>
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<tr>
<td></td>
<td>4e. At setbacks: Ensure vertical continuity or seismic separation at set-</td>
</tr>
<tr>
<td></td>
<td>backs</td>
</tr>
<tr>
<td></td>
<td>4f. Eccentric braced frames</td>
</tr>
<tr>
<td></td>
<td>4g. Flexible sliding foundation to reduce seismic vibration.</td>
</tr>
<tr>
<td>5. Structural Damping (of ultra-high</td>
<td>5a. Active damping control (tuned mass damper)</td>
</tr>
<tr>
<td>buildings)</td>
<td>5b. Visco-elastic damping</td>
</tr>
<tr>
<td></td>
<td>5c. Damping friction at bolted connections</td>
</tr>
<tr>
<td>CATEGORIES</td>
<td>INNOVATIONS</td>
</tr>
<tr>
<td>------------</td>
<td>-------------</td>
</tr>
</tbody>
</table>
| 6. Material Development  
(where soils are weak or materials unavailable) | 6a. Light weight, high strength reinforced concrete |
7b. Preconsolidation  
7c. Reinforced earth |
| 8. Composite Structure | 8a. Concrete exterior, steel interior frame  
8b. Steel plate cladding bonded to concrete members  
8c. Steel and reinforced concrete construction |
| 9. Exterior Finish (for exposed steel which corrodes) | 9a. Controlled rust steel or stainless steel |
| 10. Fire Protection (for exposed steel structural elements) | 10a. Water cooled structural members  
10b. Fire resisting paint |
| 11. Relocatable Buildings  
(Demountability) | 11a. Unit construction or modular space frame  
11b. Plastic "umbrella"  
11c. Suspension cable structure  
11d. Fabric structure |
| 12. Mass Reduction and Increased Ductility | 12a. Lightweight alloys  
12b. Plastics  
12c. Tension Structures |
| 13. Services (providing for long-term flexibility in services) | 13a. Interstitial space  
13b. Exterior shafts, ducts |
| 14. Prefabrication/Industrialization (for speedy construction, accuracy, reduction of labor) | 14a. Large scale prefabricated-prefinished structural elements  
14b. Large scale facade elements  
14c. Industrialized systems  
14d. Prefab space modules (boxes, etc.)  
14e. Post tensioning  
14f. Composite steel/precast concrete structural systems  
14g. Robotics  
14h. Computer-aided construction  
14i. Fabric structures |
In this questionnaire, we'd like you to answer five questions about this list of CATEGORIES and TYPES of innovation. They are:

1. What would you add to this list? ...Are there other categories and types of innovation you believe probable and beneficial?

2. When will each type of innovation probably occur in enough built projects so it will be treated as an available and dependable technology?

3. Which innovations do you think are most important? ...Which would confer the greatest benefits, solve the most pressing problems or have the greatest impact?

For up to ten of those innovations which you have rated as most important, tell us:

4. What are likely to be the major benefits of each?

5. What are likely to be the major constraints to earlier or more widespread acceptance of each?

THE QUESTIONS:

1. If you wish to add any categories of innovation and/or specific innovations to this list, write a short description of each and tell us what problem each tries to solve.

<table>
<thead>
<tr>
<th>DESCRIPTION OF INNOVATION</th>
<th>PROBLEM IT TRIES TO SOLVE</th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>

[8-37]
2. When will innovations occur? ....Below is a list of the innovations, on the left. (Please remember to list any you've added to the bottom of this list, on page 8.) On the right is a series of dates. Circle the number that corresponds to the date you think each innovation will have occurred in enough projects so it will be seen as an available and dependable technology.

<table>
<thead>
<tr>
<th>INNOVATION</th>
<th>WHEN AVAILABLE AND DEPENDABLE ENOUGH....</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ALREADY AVAILABLE, BY 1985 1990 1995 1995</td>
</tr>
<tr>
<td></td>
<td>DEPENDABLE</td>
</tr>
<tr>
<td>1. STIFFNESS IN HIGHRISE BLDGS.</td>
<td></td>
</tr>
<tr>
<td>1a. Frame-truss combination;</td>
<td>1</td>
</tr>
<tr>
<td>Outrigger truss; &quot;Tie-down&quot; truss</td>
<td></td>
</tr>
<tr>
<td>1b. Exterior steel plate shear walls</td>
<td>1</td>
</tr>
<tr>
<td>1c. Inclined or pyramid-shaped frame</td>
<td>1</td>
</tr>
<tr>
<td>1d. Tubular structures</td>
<td>1</td>
</tr>
<tr>
<td>2. VERTICAL FLEXIBILITY</td>
<td></td>
</tr>
<tr>
<td>2a. Megaframes</td>
<td>1</td>
</tr>
<tr>
<td>2b. Hollow tubular buildings</td>
<td>1</td>
</tr>
<tr>
<td>2c. Exterior shafts</td>
<td>1</td>
</tr>
<tr>
<td>2d. Vertically curved or folded plate walls as supports</td>
<td>1</td>
</tr>
<tr>
<td>3. WIND RESISTANT DESIGN</td>
<td></td>
</tr>
<tr>
<td>3a. Aerodynamically stable building forms</td>
<td>1</td>
</tr>
<tr>
<td>3b. Drag reduction</td>
<td>1</td>
</tr>
<tr>
<td>4. SEISMIC DESIGN</td>
<td></td>
</tr>
<tr>
<td>4a. Y-shape box columns</td>
<td>1</td>
</tr>
<tr>
<td>4b. Eliminate &quot;soft storey&quot;</td>
<td>1</td>
</tr>
<tr>
<td>4c. Shear walls graduated by height</td>
<td>1</td>
</tr>
<tr>
<td>4d. For very large buildings, ensure appropriate dimensions, or make</td>
<td>1</td>
</tr>
<tr>
<td>seismic subdivisions</td>
<td></td>
</tr>
<tr>
<td>4e. Ensure vertical continuity or seismic separation at setbacks</td>
<td>1</td>
</tr>
<tr>
<td>4f. Eccentric braced frames</td>
<td>1</td>
</tr>
<tr>
<td>4g. Flexible sliding foundation</td>
<td>1</td>
</tr>
</tbody>
</table>

A-7
<table>
<thead>
<tr>
<th>INNOVATION</th>
<th>WHEN AVAILABLE AND DEPENDABLE ENOUGH....</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ALREADY AVAILABLE, BY DEPENDABLE 1985 1990 1995 1995 NEVER</td>
</tr>
<tr>
<td>5. STRUCTURAL DAMPING</td>
<td></td>
</tr>
<tr>
<td>5a. Active damping control</td>
<td>1 2 3 4 5 6 [55]</td>
</tr>
<tr>
<td>5b. Visco-elastic damping</td>
<td>1 2 3 4 5 6 [56]</td>
</tr>
<tr>
<td>5c. Damping friction at bolted connections</td>
<td>1 2 3 4 5 6 [57]</td>
</tr>
<tr>
<td>6. MATERIAL DEVELOPMENT</td>
<td></td>
</tr>
<tr>
<td>6a. Light weight, high strength reinforced concrete</td>
<td>1 2 3 4 5 6 [58]</td>
</tr>
<tr>
<td>7. FOUNDATIONS</td>
<td></td>
</tr>
<tr>
<td>7a. Mixed-in-place stabilizers</td>
<td>1 2 3 4 5 6 [59]</td>
</tr>
<tr>
<td>7b. Preconsolidation</td>
<td>1 2 3 4 5 6 [60]</td>
</tr>
<tr>
<td>7c. Reinforced earth</td>
<td>1 2 3 4 5 6 [61]</td>
</tr>
<tr>
<td>8. COMPOSITE STRUCTURE</td>
<td></td>
</tr>
<tr>
<td>8a. Concrete exterior, steel interior frame</td>
<td>1 2 3 4 5 6 [62]</td>
</tr>
<tr>
<td>8b. Steel plate cladding bonded to concrete members</td>
<td>1 2 3 4 5 6 [63]</td>
</tr>
<tr>
<td>8c. Steel and reinforced concrete construction</td>
<td>1 2 3 4 5 6 [64]</td>
</tr>
<tr>
<td>9. EXTERIOR FINISH</td>
<td></td>
</tr>
<tr>
<td>9a. Controlled rust steel or stainless steel</td>
<td>1 2 3 4 5 6 [65]</td>
</tr>
<tr>
<td>10. FIRE PROTECTION</td>
<td></td>
</tr>
<tr>
<td>10a. Water cooled structural members</td>
<td>1 2 3 4 5 6 [66]</td>
</tr>
<tr>
<td>10b. Fire resisting paint</td>
<td>1 2 3 4 5 6 [67]</td>
</tr>
<tr>
<td>11. RELOCATABLE BUILDINGS</td>
<td></td>
</tr>
<tr>
<td>11a. Unit construction or modular space frame</td>
<td>1 2 3 4 5 6 [68]</td>
</tr>
<tr>
<td>11b. Plastic &quot;umbrella&quot;</td>
<td>1 2 3 4 5 6 [69]</td>
</tr>
<tr>
<td>11c. Suspension cable structure</td>
<td>1 2 3 4 5 6 [70]</td>
</tr>
<tr>
<td>11d. Fabric structure</td>
<td>1 2 3 4 5 6 [71]</td>
</tr>
<tr>
<td>INNOVATION</td>
<td>WHEN AVAILABLE AND DEPENDABLE ENOUGH...</td>
</tr>
<tr>
<td>------------</td>
<td>----------------------------------------</td>
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<tr>
<td></td>
<td>ALREADY AVAILABLE, DEPENDABLE</td>
</tr>
<tr>
<td>12. MASS REDUCTION AND INCREASED DUCTILITY</td>
<td></td>
</tr>
<tr>
<td>12a. Lightweight alloys</td>
<td>1</td>
</tr>
<tr>
<td>12b. Plastics</td>
<td>1</td>
</tr>
<tr>
<td>12c. Tension Structures</td>
<td>1</td>
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<tr>
<td>13. FLEXIBLE SERVICES</td>
<td></td>
</tr>
<tr>
<td>13a. Interstitial space</td>
<td>1</td>
</tr>
<tr>
<td>13b. Exterior shafts, ducts</td>
<td>1</td>
</tr>
<tr>
<td>14. PREFABRICATION/INDUSTRIALIZATION</td>
<td></td>
</tr>
<tr>
<td>14a. Large scale prefabricated-prefinished structural elements</td>
<td>1</td>
</tr>
<tr>
<td>14b. Large scale facade elements</td>
<td>1</td>
</tr>
<tr>
<td>14c. Industrialized systems</td>
<td>1</td>
</tr>
<tr>
<td>14d. Prefab space modules</td>
<td>1</td>
</tr>
<tr>
<td>14e. Post tensioning</td>
<td>1</td>
</tr>
<tr>
<td>14f. Composite steel/precast concrete structural systems</td>
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</tr>
<tr>
<td>14g. Robotics</td>
<td>1</td>
</tr>
<tr>
<td>14h. Computer-aided construction</td>
<td>1</td>
</tr>
<tr>
<td>14i. Fabric structures</td>
<td>1</td>
</tr>
<tr>
<td>15. OTHER ADDED INNOVATIONS</td>
<td></td>
</tr>
<tr>
<td>15a.</td>
<td></td>
</tr>
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<td>15b.</td>
<td></td>
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<td>15c.</td>
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<td>15d.</td>
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<td>15e.</td>
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<td>15f.</td>
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<td>15g.</td>
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<td>15h.</td>
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<td>15i.</td>
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<td>15j.</td>
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</tr>
</tbody>
</table>
3. Which innovations are likely to be the most important? Not all of these solve problems of equal importance. Tell us which you think will be the most important overall...that is, which would have the greatest benefit, solve important problems, or have substantial impact. [Some innovations probably won't happen early, but may still be very important. Don't let "when it will occur" affect your assessment of "importance".] Next to the list below, there is a scale of 0-9 for importance, with 9 being "it is of the greatest importance" and 0 being "it is of minor importance". Circle the numbers that best represent your assessment of overall importance. [Please remember to add your add-ons from page 8 to the bottom of this list on page 12.]

<table>
<thead>
<tr>
<th>INNOVATION</th>
<th>IT IS OF THE GREATEST IMPORTANCE</th>
<th>IT IS OF MINOR IMPORTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. STIFFNESS IN HIGHRISE BLDGS.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1a. Frame-truss combination; Outrigger truss; &quot;Tie-down&quot; truss</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[22]</td>
</tr>
<tr>
<td>1b. Exterior steel plate shear walls</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[23]</td>
</tr>
<tr>
<td>1c. Inclined or pyramid-shaped frame</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[24]</td>
</tr>
<tr>
<td>1d. Tubular structures</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[25]</td>
</tr>
<tr>
<td>2. VERTICAL FLEXIBILITY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2a. Megaframes</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[26]</td>
</tr>
<tr>
<td>2b. Hollow tubular buildings</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[27]</td>
</tr>
<tr>
<td>2c. Exterior shafts</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[28]</td>
</tr>
<tr>
<td>2d. Vertically curved or folded plate walls as supports</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[29]</td>
</tr>
<tr>
<td>3. WIND RESISTANT DESIGN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3a. Aerodynamically stable building forms</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[30]</td>
</tr>
<tr>
<td>3b. Drag reduction</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[31]</td>
</tr>
<tr>
<td>INNOVATION</td>
<td>IT IS OF THE GREATEST IMPORTANCE</td>
<td>IT IS OF MINOR IMPORTANCE</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>----------------------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>4. SEISMIC DESIGN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4a. Y-shape box columns</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td></td>
</tr>
<tr>
<td>4b. Eliminate &quot;soft storey&quot;</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td></td>
</tr>
<tr>
<td>4c. Shear walls graduated by height</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td></td>
</tr>
<tr>
<td>4d. For very large buildings,</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td></td>
</tr>
<tr>
<td>ensure appropriate dimensions,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>or make seismic subdivisions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4e. Ensure vertical continuity or</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td></td>
</tr>
<tr>
<td>seismic separation at setbacks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4f. Eccentric braced frames</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td></td>
</tr>
<tr>
<td>4g. Flexible sliding foundation</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td></td>
</tr>
<tr>
<td>5. STRUCTURAL DAMPING</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5a. Active damping control</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td></td>
</tr>
<tr>
<td>5b. Visco-elastic damping</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td></td>
</tr>
<tr>
<td>5c. Damping friction at bolted connections</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td></td>
</tr>
<tr>
<td>6. MATERIAL DEVELOPMENT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6a. Light weight, high strength</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td></td>
</tr>
<tr>
<td>reinforced concrete</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. FOUNDATIONS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7a. Mixed-in-place stabilizers</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td></td>
</tr>
<tr>
<td>7b. Preconsolidation</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td></td>
</tr>
<tr>
<td>7c. Reinforced earth</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td></td>
</tr>
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<td>8. COMPOSITE STRUCTURE</td>
<td></td>
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<tr>
<td>8a. Concrete exterior, steel</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<tr>
<td>interior frame</td>
<td></td>
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<tr>
<td>8b. Steel plate cladding bonded to concrete</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<tr>
<td>members</td>
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<td>8c. Steel and reinforced concrete construction</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<td>INNOVATION</td>
<td>IT IS OF THE GREATEST IMPORTANCE</td>
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<tr>
<td>9. EXTERIOR FINISH</td>
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<tr>
<td>9a. Controlled rust steel or</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<tr>
<td>stainless steel</td>
<td>[49]</td>
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<td>10. FIRE PROTECTION</td>
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<tr>
<td>10a. Water cooled structural</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<tr>
<td>members</td>
<td>[50]</td>
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<td>10b. Fire resisting paint</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<td>[51]</td>
<td></td>
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<tr>
<td>11. RELOCATABLE BUILDINGS</td>
<td></td>
<td></td>
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<tr>
<td>11a. Unit construction or modular</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<tr>
<td>space frame</td>
<td>[52]</td>
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<td>11b. Plastic &quot;umbrella&quot;</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<td>11c. Suspension cable structure</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<td>11d. Fabric structure</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<td>12. MASS REDUCTION AND INCREASED</td>
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<td>DUCTILITY</td>
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<td>12a. Lightweight alloys</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<tr>
<td>12b. Plastics</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<tr>
<td>12c. Tension Structures</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<td>13. FLEXIBLE SERVICES</td>
<td></td>
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<tr>
<td>13a. Interstitial space</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<td>13b. Exterior shafts, ducts</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<td>14. PREFABRICATION/INDUSTRIALIZATION</td>
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<tr>
<td>14a. Large scale prefabricated-</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<tr>
<td>prefabricated-prefinished structural elements</td>
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<td>14b. Large scale facade elements</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<td>14c. Industrialized systems</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<td>14d. Prefab space modules</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<td>14e. Post tensioning</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<td>14f. Composite steel/precast</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<tr>
<td>concrete structural systems</td>
<td>[66]</td>
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<tr>
<td>14g. Robotics</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<tr>
<td>14h. Computer-aided construction</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<tr>
<td>14i. Fabric structures</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<td>15j.</td>
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4. What are the benefits? For up to ten innovations you regard as the most important, tell us what you think the major benefits would be of using them in office buildings. Since GSA is a major office builder, describe any benefits you see accruing to a volume builder as well. Please list innovations by the numbers which identify them...For example, 2b refers to "hollow tubular buildings".

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<th>INNOVATION</th>
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5. For those innovations whose benefits you just described, what are the major constraints on those innovations? There are some innovations which would be more beneficial and/or would happen earlier if a major constraint were removed. Tell us which innovations these are, and for each what its constraints are. Please list each innovation by the number which identifies it... For example, 2b refers to "hollow tubular buildings".

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<tr>
<th>INNOVATION</th>
<th>MAJOR CONSTRAINTS</th>
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CARDS 6,7,8
AN EXPLORATION OF EXPECTED INNOVATIONS IN EXTERIOR WALL AND ROOF SYSTEMS OF OFFICE BUILDINGS

BACKGROUND:

Innovations in building technologies (in such areas as materials, development of sub-systems, building design, and construction methods) become widely available in the marketplace if they meet some or all of the following criteria:

° They provide higher levels of performance
° They permit uses or activities not now available or not now widespread
° They provide economies in first costs and/or in operating costs
° They satisfy new needs in the marketplace or regulatory requirements

In exploring emerging innovations in exterior wall and roof system in office buildings we wish to assess when they might occur, what their benefits might be and what constraints they operate within.

The following is a list of categories for which there is some evidence of current or near-term technological innovation related to these systems:

CATEGORIES
° INTER-BUILDING CIRCULATION AND CLIMATIC BUFFER ZONES
° NEW MATERIALS WHICH ALTER ENCLOSURE FORMS
° SOPHISTICATED DESIGN/EVALUATION PROCEDURES
° REDUCE HIGH-WIND EFFECTS
° MINIMIZE RAINWATER PENETRATION THROUGH JOINTS
° FACILITATE FUTURE FACADE CHANGES
° USE OF HOMOGENOUS, INORGANIC CELLULAR MATERIALS
° USE OF THERMAL INSULATION MATERIALS FOR EXTREME OUTSIDE OF EXTERIOR WALL
° USE OF COMPOSITE MATERIALS
° USE OF PREFAB MASS WALLS
° USE OF MINIMUM MASS SKIN COMPONENTS
° USE OF BUTT JOINT GLASS PANES
° CONSERVE OPERATIONAL ENERGY BY PASSIVE METHODS FOR MINIMIZING HEATING/COOLING/LIGHTING LOADS
° CONSERVE OPERATIONAL ENERGY BY ACTIVE SYSTEMS
° SUN CONTROL WITH EXTERIOR SHADING DEVICES
° SUN CONTROL WITH INTERIOR SHADING DEVICES
° SUN CONTROL IN WINDOW PLANE
° REFLECTION DEVICES TO BEAM DAYLIGHT INTO WORK ENVIRONMENT
° CONTROL AIR INFILTRATION/EXFILTRATION
° IMPROVE INSULATION VALUE OF WINDOWS
° NATURAL VENTILATION
° COUNTERACT UNCOMFORTABLE MEAN RADIANT TEMPERATURE
° WINDOWS AS COMPREHENSIVE ENVIRONMENT MODIFIERS
° IMPROVED PREFABRICATED INSULATING DECKS
° CONTINUOUS ELASTIC ROOFING MEMBRANE
° REDUCTION OF THERMAL SHOCK ON ROOF MEMBRANE
° UTILIZE ROOF AS FULL ENERGY PLANT
° REDUCED SOLAR LOAD ON ROOF

Within each of these categories there are some particular types or examples of innovations which have been reported in the technical journals. These are listed next to the categories they're in, starting on the next page.
<table>
<thead>
<tr>
<th>CATEGORIES</th>
<th>INNOVATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABOUT OVERALL EXTERIOR ENCLOSURE:</td>
<td></td>
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<tr>
<td>1. INTER-BUILDING CIRCULATION AND CLIMATIC BUFFER ZONES</td>
<td>1a. Pedestrian bridges (skyways) and clip-on corridors</td>
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<td></td>
<td>1b. Enclosing space between buildings</td>
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<td>1c. Solaria (designed in or clip-on)</td>
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<td>1d. Super-envelope over a group of buildings</td>
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<tr>
<td>2. NEW MATERIALS WHICH ALTER ENCLOSURE FORMS</td>
<td>2a. Modern, &quot;permanent&quot; fabric structures (cable restrained, air supported structures and tensioned fabric structures)</td>
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<tr>
<td>3. SOPHISTICATED DESIGN/EVALUATION PROCEDURES</td>
<td>3a. Computer generated facades</td>
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<td>3b. Design using solar envelopes</td>
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<td>3c. Thermographic cameras to detect leaks</td>
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<td></td>
<td>3d. Thermal modelling in design</td>
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<tr>
<td>EXTERIOR WALL</td>
<td></td>
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<tr>
<td>4. REDUCE HIGH-WIND EFFECTS</td>
<td>4a. Wind resistant design</td>
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<td>4b. &quot;Roughen&quot; perimeter surface with protrusions, setbacks, etc.</td>
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<tr>
<td>5. MINIMIZE RAINWATER PENETRATION THROUGH JOINTS</td>
<td>5a. Reduce joints</td>
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<td></td>
<td>5b. Water tighten joints</td>
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<td></td>
<td>5c. Use rainscreen/decompression chamber/drained joint</td>
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<tr>
<td>6. FACILITATE FUTURE FACADE CHANGES</td>
<td>6a. Interchangeable components and access to building's exterior</td>
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<tr>
<td>7. USE OF HOMOGENOUS, INORGANIC CELLULAR MATERIALS</td>
<td>7a. Cellular or foamed glass</td>
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<td>7b. Cellular or aerated concrete</td>
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<td>7c. Foamed ceramic bricks</td>
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<td>8. USE OF THERMAL INSULATION MATERIALS FOR EXTREME OUTSIDE OF EXTERIOR WALL</td>
<td>8a. External insulation</td>
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<td>8b. Surface coated porous fired clay</td>
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<td>8c. Insulating ceramic tiles</td>
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</table>
9. USE OF COMPOSITE MATERIALS
   9a. Surface impregnated cellular concrete
   9b. Glass fiber reinforced concrete cladding
   9c. Integrated wall panel construction systems

10. USE OF PREFAB MASS WALLS
    10a. Prefab brick wall component
    10b. Precast concrete wall component

11. USE OF MINIMUM MASS SKIN COMPONENTS
    11a. Sandwich panel systems
    11b. Ultra-thin sandwich material
    11c. Tinted, heat-absorbing, reflective glass wall
    11d. Firestop glazing

12. USE OF BUTT JOINT GLASS PANES (for continuous fenestration)
    12a. Silicone glazing sealants

13. CONSERVE OPERATIONAL ENERGY BY PASSIVE METHODS FOR MINIMIZING HEATING/COOLING/LIGHTING LOADS
    13a. Building geometry
    13b. Glazed area in wall
    13c. Heat loss through joints
    13d. Operable windows
    13e. Air-to-air heat exchangers
    13f. Thermal mass for natural cooling
    13g. Trombe walls, solaria, atria, 2nd envelope

14. CONSERVE OPERATIONAL ENERGY BY ACTIVE SYSTEMS
    14a. Absorbers/heat pump
    14b. Solar collectors
    14c. Photovoltaic cells
    14d. Sensors to automatically relate interior environmental control systems to outside conditions for optimal energy management

A-21
<table>
<thead>
<tr>
<th>CATEGORIES</th>
<th>INNOVATIONS</th>
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<tbody>
<tr>
<td>15. SUN CONTROL WITH EXTERIOR SHADING DEVICES</td>
<td>15a. Improved overhangs</td>
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<td>15b. Use of vines and plants</td>
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<td></td>
<td>15c. Use lightweight sun screen</td>
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<td></td>
<td>15d. Operable exterior venetian blinds</td>
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<td>15e. Adjustable exterior louvers</td>
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<td>15f. Fabric shades, awnings</td>
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<td>15g. Solar shutters (panels or rolling)</td>
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<td>16. SUN CONTROL WITH INTERIOR SHADING DEVICES</td>
<td>16a. Improved curtain material</td>
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<td>16b. Rollshades (tightly sealing)</td>
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<td>16c. Vinyl-coated fabric (semi-transparent or translucent)</td>
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<td>16d. Reflective synthetic films</td>
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<td>16e. Adjustable louvers, blinds</td>
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<td>17. SUN CONTROL IN WINDOW PLANE</td>
<td>17a. Venetian blinds or shades between glass</td>
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<td>17b. Coated, absorbing, tinted glass</td>
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<td>17c. Spectrally selective glass</td>
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<td>17d. Optical shutter of thermally &quot;opacifiable&quot; glass</td>
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<td>17e. Photochromic glass</td>
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<td>17f. Solar control films with adhesive backing</td>
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<td>17g. Tilted window</td>
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<td>18. REFLECTION DEVICES TO BEAM DAYLIGHT INTO</td>
<td>18a. Light shelves</td>
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<td>WORK ENVIRONMENT</td>
<td>18b. Paired reflectors with tilted window</td>
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<td>18c. Adjustable horizontal blinds</td>
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<td>19. CONTROL AIR INfiltrATION/EXFILTRATION</td>
<td>19a. Increase air tightness</td>
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<td>19b. Reduce total length of joints</td>
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<td>CATEGORIES</td>
<td>INNOVATIONS</td>
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</table>
| 20. IMPROVE INSULATION VALUE OF WINDOWS | 20a. Two parallel identical windows  
20b. Improved frame (thermal breaks, rigid vinyl)  
20c. Improved glazing area (sealed double panes with Krypton gas, heat mirror film)  
20d. Introduce dynamic insulation devices ("Beadwall", nighttime closures, blinds, interior insulating roll-up shades) |
| 21. NATURAL VENTILATION | 21a. Operable windows  
21b. Ventilation through window frame |
| 22. COUNTERACT UNCOMFORTABLE MEAN RADIANT TEMPERATURE (near window) | 22a. Increase thermal storage capacity in edge zones (mass floor, panels or ceiling tiles with phase-change core)  
22b. Radiant floor or radiant ceiling |
| 23. WINDOWS AS COMPREHENSIVE ENVIRONMENT MODIFIERS | 23a. Reversible window with blinds on one side  
23b. Multi-layer mechanized window  
23c. Automatic sensors and controls with manual overrides |
| ABOUT ROOFS AND ROOFING | |
| 24. IMPROVED PREFABRICATED INSULATING DECKS | |
| 25. IMPROVED ROOFING MEMBRANE | 25a. Single-ply continuous membranes |
| 26. REDUCTION OF THERMAL SHOCK ON ROOF MEMBRANE | 26a. Through earth covering and planting |
| 27. UTILIZE ROOF AS ENERGY PLANT | 27a. Self-tracking solar concentrators  
27b. Wind generators, etc. |
| 28. REDUCED SOLAR LOAD ON ROOF | 28a. High parapets; roof-mounted shading devices |
In this questionnaire, we'd like you to answer five questions about this list of CATEGORIES and TYPES or EXAMPLES of innovation. They are:

1. What would you add to this list? ...Are there other categories and types of innovation you believe probable and beneficial?

2. When will each type of innovation probably occur in enough built projects so it will be treated as an available and dependable technology?

3. Which innovations do you think are most important? ...Which would confer the greatest benefits, solve the most pressing problems or have the greatest impact?

For up to ten of those innovations which you have rated as most important, tell us:

4. What are likely to be the major benefits of each?

5. What are likely to be the major constraints to earlier or more widespread acceptance of each?

THE QUESTIONS:

1. If you wish to add any categories of innovation and/or specific innovations to this list, write a short description of each and tell us what problem each tries to solve.

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<th>DESCRIPTION OF INNOVATION</th>
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2. When will innovations occur? Below is a list of the innovations, on the left. (Please remember to list any you've added to the bottom of this list, on page 15.) On the right is a series of dates. Circle the number that corresponds to the date you think each innovation will have occurred in enough projects so it will be seen as an available and dependable technology.

<table>
<thead>
<tr>
<th>INNOVATION</th>
<th>WHEN AVAILABLE AND DEPENDABLE ENOUGH...</th>
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<tr>
<td></td>
<td>ALREADY AVAILABLE, BY DEPENDABLE 1985 1990 1995 1995 LATER THAN NEVER</td>
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### ABOUT OVERALL EXTERIOR ENCLOSURE:

#### 1. INTER-BUILDING CIRCULATION AND CLIMATIC BUFFER ZONES

1a. Pedestrian bridges (skyways) and clip-on corridors

1b. Enclosing space between buildings

1c. Solaria (designed in or clip-on)

1d. Super-envelope over a group of buildings

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<tr>
<td>Pedestrian bridges (skyways) and clip-on corridors</td>
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<tr>
<td>Enclosing space between buildings</td>
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<tr>
<td>Solaria (designed in or clip-on)</td>
<td>1</td>
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<tr>
<td>Super-envelope over a group of buildings</td>
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#### 2. NEW MATERIALS WHICH ALTER ENCLOSURE FORMS

2a. Modern, "permanent" fabric structures (cable restrained, air supported structures and tensioned fabric structures)

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<td>Modern, &quot;permanent&quot; fabric structures (cable restrained, air supported structures and tensioned fabric structures)</td>
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#### 3. SOPHISTICATED DESIGN/EVALUATION PROCEDURES

3a. Computer generated facades

3b. Design using solar envelopes

3c. Thermographic cameras to detect leaks

3d. Thermal modelling in design

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<tr>
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<tr>
<td>Design using solar envelopes</td>
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<tr>
<td>Thermographic cameras to detect leaks</td>
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<td>Thermal modelling in design</td>
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4. REDUCE HIGH-WIND EFFECTS

4a. Wind resistant design

4b. "Roughen" perimeter surface with protrusions, setbacks, etc.

5. MINIMIZE RAINWATER PENETRATION THROUGH JOINTS

5a. Reduce joints

5b. Water tighten joints

5c. Use rainscreen/decompression chamber/drained joint

6. FACILITATE FUTURE FACADE CHANGES

6a. Interchangeable components and access to building's exterior

7. USE OF HOMOGENOUS, INORGANIC CELLULAR MATERIALS

7a. Cellular or foamed glass

7b. Cellular or aerated concrete

7c. Foamed ceramic bricks

8. USE OF THERMAL INSULATION MATERIALS FOR EXTREME OUTSIDE OF EXTERIOR WALL

8a. External insulation

8b. Surface coated porous fired clay

8c. Insulating ceramic tiles

A-27
9. USE OF COMPOSITE MATERIALS
   9a. Surface impregnated cellular concrete 1 2 3 4 5 6 [59]
   9b. Glass fiber reinforced concrete cladding 1 2 3 4 5 6 [60]
   9c. Integrated wall panel construction systems 1 2 3 4 5 6 [61]

10. USE OF PREFAB MASS WALLS
    10a. Prefab brick wall component 1 2 3 4 5 6 [62]
    10b. Precast concrete wall component 1 2 3 4 5 6 [63]

11. USE OF MINIMUM MASS SKIN COMPONENTS
    11a. Sandwich panel systems 1 2 3 4 5 6 [64]
    11b. Ultra-thin sandwich material 1 2 3 4 5 6 [65]
    11c. Tinted, heat-absorbing, reflective glass wall 1 2 3 4 5 6 [66]
    11d. Firestop glazing 1 2 3 4 5 6 [67]

12. USE OF BUTT JOINT GLASS PANES (for continuous fenestration)
    12a. Silicone glazing sealants 1 2 3 4 5 6 [68]

13. CONSERVE OPERATIONAL ENERGY BY PASSIVE METHODS FOR METHODS FOR MINIMIZING HEATING/COOLING/LIGHTING LOADS
    13a. Building geometry 1 2 3 4 5 6 [69]
    13b. Glazed area in wall 1 2 3 4 5 6 [70]
    13c. Heat loss through joints 1 2 3 4 5 6 [71]
    13d. Operable windows 1 2 3 4 5 6 [72]
    13e. Air-to-air heat exchangers 1 2 3 4 5 6 [73]
    13f. Thermal mass for natural cooling 1 2 3 4 5 6 [74]
    13g. Trombe walls, solaria, atria, 2nd envelope 1 2 3 4 5 6 [75]
### WHEN AVAILABLE AND DEPENDABLE ENOUGH....

<table>
<thead>
<tr>
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<th>BY 1990</th>
<th>BY 1995</th>
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<td>14a. Absorbers/heat pump</td>
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<td>14b. Solar collectors</td>
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<td>14c. Photovoltaic cells</td>
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<tr>
<td>14d. Sensors to automatically relate interior environmental control systems to outside conditions for optimal energy management</td>
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</table>

| **15. SUN CONTROL WITH EXTERIOR SHADING DEVICES** | | | | | |
| 15a. Improved overhangs | 1 | 2 | 3 | 4 | 5 | 6 [3] |
| 15b. Use of vines and plants | 1 | 2 | 3 | 4 | 5 | 6 [4] |
| 15c. Use lightweight sun screen | 1 | 2 | 3 | 4 | 5 | 6 [5] |
| 15d. Operable exterior venetian blinds | 1 | 2 | 3 | 4 | 5 | 6 [6] |
| 15e. Adjustable exterior louvers | 1 | 2 | 3 | 4 | 5 | 6 [7] |
| 15f. Fabric shades, awnings | 1 | 2 | 3 | 4 | 5 | 6 [8] |
| 15g. Solar shutters (panels or rolling) | 1 | 2 | 3 | 4 | 5 | 6 [9] |

| **16. SUN CONTROL WITH INTERIOR SHADING DEVICES** | | | | | |
| 16a. Improved curtain material | 1 | 2 | 3 | 4 | 5 | 6 [10] |
| 16b. Rollshades (tightly sealing) | 1 | 2 | 3 | 4 | 5 | 6 [11] |
| 16c. Vinyl-coated fabric (semi-transparent or translucent) | 1 | 2 | 3 | 4 | 5 | 6 [12] |
| 16d. Reflective synthetic films | 1 | 2 | 3 | 4 | 5 | 6 [13] |
| 16e. Adjustable louvers, blinds | 1 | 2 | 3 | 4 | 5 | 6 [14] |
### WHEN AVAILABLE AND DEPENDABLE ENOUGH....

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<td>17a. Venetian blinds or shades between glass</td>
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<td>17b. Coated, absorbing, tinted glass</td>
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<td>17c. Spectrally selective glass</td>
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<td>17d. Optical shutter of thermally &quot;opacifiable&quot; glass</td>
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<td>17e. Photochromic glass</td>
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<td>17f. Solar control films with adhesive backing</td>
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<td>17g. Tilted window</td>
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<td>2</td>
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<td>18. REFLECTION DEVICES TO BEAM DAYLIGHT INTO WORK ENVIRONMENT</td>
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<td>18a. Light shelves</td>
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<td>18b. Paired reflectors with tilted window</td>
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<td>4</td>
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<td>6 [23]</td>
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<tr>
<td>18c. Adjustable horizontal blinds</td>
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<td>6 [24]</td>
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<td>19. CONTROL AIR INFILTRATION/EXFILTRATION</td>
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<td>19a. Increase air tightness</td>
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<td>4</td>
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<td>6 [25]</td>
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<td>19b. Reduce total length of joints</td>
<td>1</td>
<td>2</td>
<td>3</td>
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<td>6 [26]</td>
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<tr>
<td>20. IMPROVE INSULATION VALUE OF WINDOWS</td>
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<tr>
<td>20a. Two parallel identical windows</td>
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</tr>
<tr>
<td>20b. Improved frame (thermal breaks, rigid vinyl)</td>
<td>1</td>
<td>2</td>
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<tr>
<td>20c. Improved glazing area (sealed double panes with Krypton gas, heat mirror film)</td>
<td>1</td>
<td>2</td>
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<tr>
<td>20d. Introduce dynamic insulation devices (&quot;Beadwall&quot;, night-time closures, blinds, interior insulating roll-up shades)</td>
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<td>21a. Operable windows</td>
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<td>21b. Ventilation through window frame</td>
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<td>22. COUNTERACT UNCOMFORTABLE MEAN RADIANT TEMPERATURE (near window)</td>
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<td>22a. Increase thermal storage capacity in edge zones (mass floor, panel or ceiling tiles with phase-change core)</td>
<td>1 2 3 4 5 6 [33]</td>
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<td>22b. Radiant floor or radiant ceiling</td>
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<td>23b. Multi-layer mechanized window</td>
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<td>23c. Automatic sensors and controls with manual overrides</td>
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<td>25a. Single-ply continuous membranes</td>
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<td>26. REDUCTION OF THERMAL SHOCK ON ROOF MEMBRANE</td>
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<td>26a. Through earth covering and planting</td>
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<td>28. REDUCED SOLAR LOAD ON ROOF</td>
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<td>28a. High parapets; roof-mounted shading devices</td>
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<td>5</td>
<td>6</td>
<td>[53]</td>
</tr>
</tbody>
</table>
3. Which innovations are likely to be the most important? Not all of these solve problems of equal importance. Tell us which you think will be the most important overall...that is, which would have the greatest benefit, solve important problems, or have substantial impact. [Some innovations probably won't happen early, but may still be very important. Don't let "when it will occur" affect your assessment of "importance".] Next to the list below, there is a scale of 0-9 for importance, with 9 being "it is of the greatest importance" and 0 being "it is of minor importance". Circle the numbers that best represent your assessment of overall importance. [Please remember to add your add-ons from page 15 to the bottom of this list, on page 21.]

<table>
<thead>
<tr>
<th>INNOVATION</th>
<th>IT IS OF THE GREATEST IMPORTANCE</th>
<th>IT IS OF MINOR IMPORTANCE</th>
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</thead>
<tbody>
<tr>
<td>ABOUT OVERALL EXTERIOR ENCLOSURE:</td>
<td></td>
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<tr>
<td>1. INTER-BUILDING CIRCULATION AND CLIMATIC BUFFER ZONES</td>
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</tr>
<tr>
<td>1a. Pedestrian bridges (skyways) and clip-on corridors</td>
<td>9 8 7 6 5 4 3 2 1 0 [54]</td>
<td></td>
</tr>
<tr>
<td>1b. Enclosing space between buildings</td>
<td>9 8 7 6 5 4 3 2 1 0 [55]</td>
<td></td>
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<tr>
<td>1c. Solaria (designed in or clip-on)</td>
<td>9 8 7 6 5 4 3 2 1 0 [56]</td>
<td></td>
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<tr>
<td>1d. Super-envelope over a group of buildings</td>
<td>9 8 7 6 5 4 3 2 1 0 [57]</td>
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</tr>
<tr>
<td>2. NEW MATERIALS WHICH ALTER ENCLOSURE FORMS</td>
<td></td>
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</tr>
<tr>
<td>2a. Modern, &quot;permanent&quot; fabric structures (cable restrained, air supported structures and tensioned fabric structures)</td>
<td>9 8 7 6 5 4 3 2 1 0 [58]</td>
<td></td>
</tr>
<tr>
<td>3. SOPHISTICATED DESIGN/EVALUATION PROCEDURES</td>
<td></td>
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<tr>
<td>3a. Computer generated facades</td>
<td>9 8 7 6 5 4 3 2 1 0 [59]</td>
<td></td>
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<tr>
<td>3b. Design using solar envelopes</td>
<td>9 8 7 6 5 4 3 2 1 0 [60]</td>
<td></td>
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<tr>
<td>3c. Thermographic cameras to detect leaks</td>
<td>9 8 7 6 5 4 3 2 1 0 [61]</td>
<td></td>
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<tr>
<td>3d. Thermal modelling in design</td>
<td>9 8 7 6 5 4 3 2 1 0 [62]</td>
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</tbody>
</table>

**EXTERIOR WALL**

4. **REDUCE HIGH-WIND EFFECTS**
   4a. Wind resistant design 9 8 7 6 5 4 3 2 1 0 [63]
   4b. "Roughen" perimeter surface with protrusions, setbacks, etc. 9 8 7 6 5 4 3 2 1 0 [64]

5. **MINIMIZE RAINWATER PENETRATION THROUGH JOINTS**
   5a. Reduce joints 9 8 7 6 5 4 3 2 1 0 [65]
   5b. Water tighten joints 9 8 7 6 5 4 3 2 1 0 [66]
   5c. Use rainscreen/decompression chamber/drained joint 9 8 7 6 5 4 3 2 1 0 [67]

6. **FACILITATE FUTURE FACADE CHANGES**
   6a. Interchangeable components and access to building's exterior 9 8 7 6 5 4 3 2 1 0 [68]

7. **USE OF HOMOGENOUS, INORGANIC CELLULAR MATERIALS**
   7a. Cellular or foamed glass 9 8 7 6 5 4 3 2 1 0 [69]
   7b. Cellular or aerated concrete 9 8 7 6 5 4 3 2 1 0 [70]
   7c. Foamed ceramic bricks 9 8 7 6 5 4 3 2 1 0 [71]

8. **USE OF THERMAL INSULATION MATERIALS FOR EXTREME OUTSIDE OF EXTERIOR WALL**
   8a. External insulation 9 8 7 6 5 4 3 2 1 0 [72]
   8b. Surface coated porous fired clay 9 8 7 6 5 4 3 2 1 0 [73]
   8c. Insulating ceramic tiles 9 8 7 6 5 4 3 2 1 0 [74]
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<tr>
<th>INNOVATION</th>
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<tbody>
<tr>
<td>9. USE OF COMPOSITE MATERIALS</td>
<td></td>
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<tr>
<td>9a. Surface impregnated cellular concrete</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[75]</td>
</tr>
<tr>
<td>9b. Glass fiber reinforced concrete cladding</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[76]</td>
</tr>
<tr>
<td>9c. Integrated wall panel construction systems</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[77]</td>
</tr>
<tr>
<td>10. USE OF PREFAB MASS WALLS</td>
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<tr>
<td>10a. Prefab brick wall component</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[78]</td>
</tr>
<tr>
<td>10b. Precast concrete wall component</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[79]</td>
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<tr>
<td>11. USE OF MINIMUM MASS SKIN COMPONENTS</td>
<td></td>
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<tr>
<td>11a. Sandwich panel systems</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[3]</td>
</tr>
<tr>
<td>11b. Ultra-thin sandwich material</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[4]</td>
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<tr>
<td>11c. Tinted, heat-absorbing, reflective glass wall</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[5]</td>
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<tr>
<td>11d. Firestop glazing</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[6]</td>
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<tr>
<td>12. USE OF BUTT JOINT GLASS PANES (for continuous fenestration)</td>
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<tr>
<td>12a. Silicone glazing sealants</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<td>----------------------------------------------------------------------------</td>
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<tr>
<td>13. CONSERVE OPERATIONAL ENERGY BY PASSIVE METHODS FOR MINIMIZING HEATING/COOLING/LIGHTING LOADS</td>
<td></td>
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<tr>
<td>13a. Building geometry</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[8]</td>
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<tr>
<td>13b. Glazed area in wall</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[9]</td>
</tr>
<tr>
<td>13c. Heat loss through joints</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[10]</td>
</tr>
<tr>
<td>13d. Operable windows</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[11]</td>
</tr>
<tr>
<td>13e. Air-to-air heat exchangers</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[12]</td>
</tr>
<tr>
<td>13f. Thermal mass for natural cooling</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[13]</td>
</tr>
<tr>
<td>13g. Trombe walls, solaria, atria, 2nd envelope</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[14]</td>
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<tr>
<td>14. CONSERVE OPERATIONAL ENERGY BY ACTIVE SYSTEMS</td>
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<tr>
<td>14a. Absorbers/heat pump</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<tr>
<td>14b. Solar collectors</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[16]</td>
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<tr>
<td>14c. Photovoltaic cells</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[17]</td>
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<tr>
<td>14d. Sensors to automatically relate interior environmental control systems to outside conditions for optimal energy management</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[18]</td>
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<tr>
<td>15. SUN CONTROL WITH EXTERIOR SHADING DEVICES</td>
<td></td>
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<tr>
<td>15a. Improved overhangs</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[19]</td>
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<tr>
<td>15b. Use of vines and plants</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[20]</td>
</tr>
<tr>
<td>15c. Use lightweight sun screen</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[21]</td>
</tr>
<tr>
<td>15d. Operable exterior venetian blinds</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[22]</td>
</tr>
<tr>
<td>15e. Adjustable exterior louvers</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[23]</td>
</tr>
<tr>
<td>15f. Fabric shades, awnings</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[24]</td>
</tr>
<tr>
<td>15g. Solar shutters (panels or rolling)</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[25]</td>
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<tr>
<td>16. SUN CONTROL WITH INTERIOR SHADING DEVICES</td>
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<tr>
<td>16a. Improved curtain material</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[26]</td>
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<tr>
<td>16b. Rollshades (tightly sealing)</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[27]</td>
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<tr>
<td>16c. Vinyl-coated fabric (semi-transparent or translucent)</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[28]</td>
</tr>
<tr>
<td>16d. Reflective synthetic films</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[29]</td>
</tr>
<tr>
<td>16e. Adjustable louvers, blinds</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[30]</td>
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<tr>
<td>17. SUN CONTROL IN WINDOW PLANE</td>
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<tr>
<td>17a. Venetian blinds or shades between glass</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[31]</td>
</tr>
<tr>
<td>17b. Coated, absorbing, tinted glass</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[32]</td>
</tr>
<tr>
<td>17c. Spectrally selective glass</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[33]</td>
</tr>
<tr>
<td>17d. Optical shutter of thermally &quot;opacifiable&quot; glass</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[34]</td>
</tr>
<tr>
<td>17e. Photochromic glass</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[35]</td>
</tr>
<tr>
<td>17f. Solar control films with adhesive backing</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[36]</td>
</tr>
<tr>
<td>17g. Tilted window</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[37]</td>
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<tr>
<td>18. REFLECTION DEVICES TO BEAM DAYLIGHT INTO WORK ENVIRONMENT</td>
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<tr>
<td>18a. Light shelves</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[38]</td>
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<tr>
<td>18b. Paired reflectors with tilted window</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[39]</td>
</tr>
<tr>
<td>18c. Adjustable horizontal blinds</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[40]</td>
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<tr>
<td>19. CONTROL AIR INFILTRATION/EXFILTRATION</td>
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<tr>
<td>19a. Increase air tightness</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[41]</td>
</tr>
<tr>
<td>19b. Reduce total length of joints</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[42]</td>
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A-37
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<th>IT IS OF THE GREATEST IMPORTANCE</th>
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<tbody>
<tr>
<td>20. IMPROVE INSULATION VALUE OF WINDOWS</td>
<td></td>
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</tr>
<tr>
<td>20a. Two parallel identical windows</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<tr>
<td>20b. Improved frame (thermal breaks, rigid vinyl)</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td></td>
</tr>
<tr>
<td>20c. Improved glazing area (sealed double panes with Krypton gas, heat mirror film)</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td></td>
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<tr>
<td>20d. Introduce dynamic insulation devices (&quot;Beadwall&quot;, night-time closures, blinds, interior insulating roll-up shades)</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<tr>
<td>21. NATURAL VENTILATION</td>
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<tr>
<td>21a. Operable windows</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<tr>
<td>21b. Ventilation through window frame</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<td>22. COUNTERACT UNCOMFORTABLE MEAN RADIANT TEMPERATURE (near window)</td>
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<tr>
<td>22a. Increase thermal storage capacity in edge zones (mass floor, panel or ceiling tiles with phase-change core)</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<tr>
<td>22b. Radiant floor or radiant ceiling</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<tr>
<td>23. WINDOWS AS COMPREHENSIVE ENVIRONMENT MODIFIERS</td>
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<tr>
<td>23a. Reversible window with blinds on one side</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<tr>
<td>23b. Multi-layer mechanized window</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td></td>
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<tr>
<td>23c. Automatic sensors and controls with manual overrides</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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<td>INNOVATION</td>
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<tr>
<td>ABOUT ROOFS AND ROOFING</td>
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<tr>
<td>24. IMPROVED PREFABRICATED INSULATING DECKS</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[54]</td>
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<td>25. CONTINUOUS ELASTIC ROOFING MEMBRANE</td>
<td></td>
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<tr>
<td>25a. Singly-ply continuous membranes</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[55]</td>
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<td>26. REDUCTION OF THERMAL SHOCK ON ROOF MEMBRANE</td>
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<tr>
<td>26a. Through earth covering and planting</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[56]</td>
</tr>
<tr>
<td>27. UTILIZE ROOF AS ENERGY PLANT</td>
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<tr>
<td>27a. Self-tracking solar concentrators</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[57]</td>
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<tr>
<td>27b. Wind generators, etc.</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[58]</td>
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<tr>
<td>28. REDUCED SOLAR LOAD ON ROOF</td>
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<tr>
<td>28a. High parapets; roof-mounted shading devices</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[59]</td>
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<td>29. OTHER ADDED INNOVATIONS</td>
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<td>29a.</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[60]</td>
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<td>29b.</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[61]</td>
</tr>
<tr>
<td>29c.</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[62]</td>
</tr>
<tr>
<td>29d.</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
<td>[63]</td>
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<td>29e.</td>
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<td>29f.</td>
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<td>29h.</td>
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<td>29i.</td>
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<td>29j.</td>
<td>9 8 7 6 5 4 3 2 1 0</td>
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A-39
4. What are the benefits? For up to ten (10) innovations you rated as most important, tell us what you think the major benefits would be of using them in office buildings. Since GSA is a major office builder, describe any benefits you see accruing to a volume builder as well. Please list innovation by the numbers which identify them...for example, 3c refers to "thermographic cameras".

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<th>MAJOR BENEFITS</th>
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CARDS 4,5,6

A-40
5. For those innovations whose benefits you just described, what are the major constraints on those innovations? There are some innovations which would be more beneficial and/or would happen earlier if a major constraint was removed. Tell us which innovations these are and for each, what its constraints are. Please list each innovation by the number which identifies it...for example, 3c refers to "thermographic cameras."

INNOVATION | MAJOR CONSTRAINTS
--- | ---

CARDS 7, 8, 9
APPENDIX B. Basic Data
### Table A1. Estimates of Availability of Structural Innovations

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<td><strong>1 - Stiffness in Highrise Buildings</strong></td>
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<tr>
<td>1a-Frame-truss combination; Outrigger truss; &quot;Tie-down&quot; truss</td>
<td>59.5</td>
<td>16.2</td>
<td>16.2</td>
<td>2.7</td>
<td>5.4</td>
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<tr>
<td>1b-Exterior steel plate shear walls</td>
<td>40.0</td>
<td>5.7</td>
<td>25.7</td>
<td>5.7</td>
<td>8.6</td>
<td>14.3</td>
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<tr>
<td>1c-Inclined or pyramid-shaped frame</td>
<td>51.3</td>
<td>15.4</td>
<td>7.7</td>
<td>10.3</td>
<td>7.7</td>
<td>7.7</td>
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<td>1d-Tubular structures</td>
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<td>12.5</td>
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<td><strong>2 - Vertical Flexibility</strong></td>
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<td>2a-Megaframes</td>
<td>19.4</td>
<td>11.1</td>
<td>30.6</td>
<td>11.1</td>
<td>25.0</td>
<td>2.8</td>
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Table A2. Estimates of Importance of Structural Innovations

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<td>14 - PREFABRICATION/INDUSTRIALIZATION</td>
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<td>14a-Large scale prefabricated-pre-finished structural elements</td>
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<td>14b-Large scale facade elements</td>
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<td>14f-Composite steel/precast concrete structural systems</td>
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<td>14g-Robotics</td>
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<td>14h-Computer-aided construction</td>
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<td>14i-Fabric structures</td>
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Table A3. Estimates of Availability of Enclosure Innovations

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<th>BY 1990 (PCT)</th>
<th>BY 1995 (PCT)</th>
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<th>NEVER (PCT)</th>
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<tr>
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<td>1c-Solaria (designed in or clip-on)</td>
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<td>5a-Reduce joints</td>
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<td>5b-Water tighten joints</td>
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### Table A3. Estimates of Availability of Enclosure Innovations (Cont.)

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<td>5c-Use rainscreen/decompression chamber/drained joint</td>
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<td>7b-Cellular or aerated concrete</td>
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<td>7c-Foamed ceramic bricks</td>
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<td>8 - USE OF THERMAL INSULATION MATERIALS</td>
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<td>8a-External insulation</td>
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<td>8b-Surface coated porous fire clay</td>
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<td>8c-Insulating ceramic tiles</td>
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<td>10a-Prefab brick wall component</td>
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Table A3. Estimates of Availability of Enclosure Innovations (Cont.)

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<th>LATER THAN 1995 (PCT)</th>
<th>NEVER (PCT)</th>
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<td>11 -USE OF MINIMUM MASS SKIN COMPONENTS</td>
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<td>11a-Sandwich panel systems</td>
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<td>11b-Ultra-thin sandwich material</td>
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<td>11c-Tinted, heat-absorbing, reflective glass wall</td>
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<td>11d-Firestop glazing</td>
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<td>12 -USE OF BUTT JOINT GLASS PANES (for continuous fenestration)</td>
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<td>12a-Silicone glazing sealants</td>
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<td>13a-Building geometry</td>
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<td>13b-Glazed area in wall</td>
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<td>13c-Heat loss through joints</td>
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<td>13d-Operable windows</td>
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<td>13e-Air-to-air heat exchangers</td>
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<td>13f-Thermal mass for natural cooling</td>
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<td>13g-Trombe walls, solaria, atria, 2nd envelope</td>
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<td>14 -CONSERVE OPERATIONAL ENERGY BY ACTIVE SYSTEMS</td>
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Table A3. Estimates of Availability of Enclosure Innovations (Cont.)

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<th>DEPENDABLE BY 1985 (PCT)</th>
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<td>14a-Absorbers/heat pump</td>
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<td>15.4</td>
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<td>14c-Photovoltaic cells</td>
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<td>30.8</td>
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<td>14d-Sensors to automatically relate interior envir. to outside cond.</td>
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<td>30.8</td>
<td>23.1</td>
<td>15.4</td>
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15-SUN CONTROL WITH EXTERIOR SHADING DEVICES

| 15a-Improve overhangs | 79.3 | 3.4 | 17.2 |
| 15b-Use of vines and plants | 67.9 | 10.7 | 10.7 | 3.6 | 7.1 |
| 15c-Use lightweight sun screen | 50.0 | 25.0 | 21.4 | 3.6 |
| 15d-Operable exterior venetian blinds | 33.3 | 25.0 | 25.0 | 4.2 | 12.5 |
| 15e-Adjustable exterior louvers | 34.6 | 30.8 | 26.9 | 3.8 | 3.8 |
| 15f-Fabric shades, awnings | 89.7 | 3.4 | 6.9 |
| 15g-Solar shutters (panels or rolling) | 23.1 | 19.2 | 42.3 | 3.8 | 3.8 | 7.7 |

16-SUN CONTROL WITH INTERIOR SHADING DEVICE

<p>| 16a-Improved curtain material | 42.3 | 30.6 | 23.1 | 3.8 |
| 16b-Rollshades (tightly sealing) | 33.3 | 29.6 | 29.6 | 3.7 | 3.7 |
| 16c-Vinyl-coated fabric (semi-transparent or translucent) | 36.0 | 20.0 | 32.0 | 4.0 | 8.0 |
| 16d-Reflective synthetic films | 35.7 | 35.7 | 17.9 | 3.6 | 7.1 |</p>
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<td>16 -SUN CONTROL IN WINDOW PLANE</td>
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<td>17a-Venetian blinds or shades between glass</td>
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<td>17b-Coated, absorbing, tinted glass</td>
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<td>17c-Spectrally selective glass</td>
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<td>17d-Optical shutter of thermally &quot;opacifiable&quot; glass</td>
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<td>17e-Photochromic glass</td>
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<td>17f-Solar control films with adhesive backing</td>
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<td>18b-Paired reflectors with tilted window</td>
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<td>18c-Adjustable horizontal blinds</td>
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<td>19 -CONTROL AIR INFILTRATION/EXFILTRATION</td>
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<td>20 - IMPROVE INSULATION VALUE OF WINDOWS</td>
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<td>20a-Two parallel identical windows</td>
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<td>20b-Improve frame (thermal breaks, rigid: vinyl)</td>
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<td>20c-Improve glazing area (double panes w/ Krypton gas, heated mirror film)</td>
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<td>20d-Introduce dynamic insulation devices: (&quot;Beadwall&quot;, blinds, roll-up shades)</td>
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<td>21 - NATURAL VENTILATION</td>
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<td>21a-Operable windows</td>
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<td>21b-Ventilation through window frame</td>
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<td>22 - COUNTERACT UNCOMFORTABLE MEAN RADIANT TEMPERATURE (near window)</td>
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<td>22a-Increase thermal storage capacity in edge zones (phase-change panels)</td>
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<td>22b-Radiant floor or radiant ceiling</td>
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<td>23a-Reversible window with blinds on one side</td>
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<td>23c-Automatic sensors and controls with manual overrides</td>
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Table A3. Estimates of Availability of Enclosure Innovations (Cont.)

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<th>BY 1985 (PCT)</th>
<th>BY 1990 (PCT)</th>
<th>BY 1995 (PCT)</th>
<th>LATER THAN 1995 (PCT)</th>
<th>NEVER (PCT)</th>
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<td>26 -REDUCTION OF THERMAL SHOCK ON ROOF MEMBRANE</td>
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<td>26a-Through earth covering and planting</td>
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<td>27 -UTILIZE ROOF AS ENERGY PLANT</td>
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<td>27a-Self-tracking solar concentrators</td>
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<td>18.5</td>
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<td>27b-Wind generators, etc.</td>
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<td>28 -REDUCED SOLAR LOAD ON ROOF</td>
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<td>28a-High parapets; roof-mounted shading devices</td>
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<td>1 - INTER-BUILDING CIRCULATION AND CLIMATIC BUFFER ZONES</td>
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<td>1a - Pedestrian bridges (skyways) and clip-on corridors</td>
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<td>1b - Enclosing space between buildings</td>
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<td>1c - Solaria (designed in or clip-on)</td>
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<td>1d - Super-envelope over a group of buildings</td>
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<td>2 - NEW MATERIALS WHICH ALTER ENCLOSURE FORMS</td>
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<td>2a - Modern &quot;permanent&quot; fabric structures (cable restrain, air support, etc.)</td>
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<td>3 - SOPHISTICATED DESIGN/EVALUATION PROCEDURES</td>
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<td>3b - Design using solar envelopes</td>
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<td>3c - Thermographic cameras to detect leaks</td>
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<td>3d - Thermal modelling in design</td>
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<td>4 - REDUCE HIGH-WIND EFFECTS</td>
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<td>4a - Wind resistant design</td>
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<td>4b - &quot;Roughen&quot; perimeter surface with protrusions, setbacks, etc.</td>
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<td>5 - MINIMIZE RAINWATER PENETRATION THROUGH JOINTS</td>
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<td>5a - Reduce joints</td>
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<td>5b - Water tighten joints</td>
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Table A4. Estimates of Importance of Enclosure Innovations (Cont.)

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<th>GREATEST IMPORTANCE (PCT)</th>
<th>MINOR IMPORTANCE (PCT)</th>
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<td>5c-Use rainscreen/decompression chamber/drained joint</td>
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<td>6.9 10.3 17.2 17.2 24.1 3.4 6.9 3.4</td>
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<td>6 -FACILITATE FUTURE FACADE CHANGES</td>
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<td>6a-Interchangeable components and access to building's exterior</td>
<td>3.4 27.6 10.3 27.6 6.9 10.3 10.3 3.4</td>
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<td>7 -USE OF HOMOGENOUS, INORGANIC CELLULAR MATERIALS</td>
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<td>7a-Cellular or foamed glass</td>
<td>6.9 10.3 20.7 17.2 17.2 13.8 3.4 3.4</td>
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<td>7b-Cellular or aerated concrete</td>
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<td>7c-Poamed ceramic bricks</td>
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<td>20.7 13.8 27.6 17.2 3.4 6.9 10.3 10.3</td>
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<td>8 -USE OF THERMAL INSULATION MATERIALS FOR EXTREME OUTSIDE OF EXTERIOR WALL</td>
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<td>8a-External insulation</td>
<td>31.0 10.3 10.3 3.4 13.8 17.2 6.9 3.4</td>
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<td>8b-Surface coated porous fire clay</td>
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<td>20.7 13.8 31.0 6.9 13.8 6.9 3.4 3.4</td>
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<td>8c-Insulating ceramic tiles</td>
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<td>20.7 13.8 31.0 13.8 13.8 3.4 3.4 3.4</td>
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<td>9 -USE OF COMPOSITE MATERIALS</td>
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<td>9a-Surface impregnated cellular concrete</td>
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<td>9b-Glass fiber reinforced concrete cladding</td>
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<td>9c-Integrated wall panel construction systems</td>
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<td>10 -USE OF PREFAB MASS WALLS</td>
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<td>10a-Prefab brick wall component</td>
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Table A4. Estimates of Importance of Enlosure Innovations (Cont.)

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<td>11a-Sandwich panel systems</td>
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<td>11c-Tinted, heat-absorbing, reflective glass wall</td>
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<td>11d-Firestop glazing</td>
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<td>12 USE OF BUTT JOINT GLASS PANES (for continuous fenestration)</td>
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<td>12a-Silicone glazing sealants</td>
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<td>13 PASSIVE METHODS FOR REDUCING HEAT/G/C/ LIGHT/G</td>
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<td>13d-Operable windows</td>
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<td>13e-Air-to-air heat exchangers</td>
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<td>13f-Thermal mass for natural cooling</td>
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<td>13g-Trombe walls, solaria, atria, 2nd envelope</td>
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<td>14 CONSERVE OPERATIONAL ENERGY BY</td>
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Table A4. Estimates of Importance of Enclosure Innovations (Cont.)

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<td>ACTIVE SYSTEMS</td>
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<td>14a-Absorbers/heat pump</td>
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<td>14b-Solar collectors</td>
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<td>14c-Photovoltaic cells</td>
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<td>14d-Sensors to automatically relate interior env. to outside cond.</td>
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<td>15- SUN CONTROL WITH EXTERIOR SHADING DEVICES</td>
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<td>15a-Improve overhangs</td>
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<td>15b-Use of vines and plants</td>
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<td>15c-Use lightweight sun screen</td>
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<td>15d-Operable exterior venetian blinds</td>
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<td>15e-Adjustable exterior louvers</td>
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<td>15f-Fabric shades, awnings</td>
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<td>15g-Solar shutters (panels or rolling)</td>
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<td>16-SUN CONTROL WITH INTERIOR SHADING DEVICE</td>
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<td>16a-Improved curtain material</td>
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<td>16b-Rolleshades (tightly sealing)</td>
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<td>16c-Vinyl-coated fabric (semi-transparent or translucent)</td>
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<td>16d-Reflective synthetic films</td>
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<td>16e-Adjustable louvers, blinds</td>
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<td>17 - SUN CONTROL IN WINDOW PLANE</td>
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<td>17a-Venetian blinds or shades between glass</td>
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<td>17b-Coated, absorbing, tinted glass</td>
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<td>17c-Spectrally selective glass</td>
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<td>17d-Optical shutter of thermally &quot;opacifiable&quot; glass</td>
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<td>17e-Photochromic glass</td>
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<tr>
<td>17f-Solar control films with adhesive backing</td>
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<tr>
<td>17g-Tilted window</td>
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<td>18 - REFLECTION DEVICES TO BEAM DAYLIGHT INTO WORK ENVIRONMENT</td>
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<td>18a-Light shelves</td>
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<td>18b-Paired reflectors with tilted window</td>
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<td>18c-Adjustable horizontal blinds</td>
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<td>10.3</td>
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<td>19 - CONTROL AIR INFILTRATION/EXFILTRATION</td>
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<td>19a-Increase air tightness</td>
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<tr>
<td>19b-Reduce total length of joints</td>
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Table A4. Estimates of Importance of Enclosure Innovations (Cont.)

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<tr>
<td>20 - IMPROVE INSULATION VALUE OF WINDOWS</td>
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<tr>
<td>20a - Two parallel identical windows</td>
<td>10.3 17.2 13.8 10.3 10.3 6.9 6.9 10.3</td>
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<tr>
<td>20b - Improve frame (thermal breaks, rigid vinyl)</td>
<td>10.3 27.6 17.2 20.7 13.8</td>
<td>3.4 6.9</td>
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<tr>
<td>20c - Improve glazing area (double panes w/ Krypton gas, heated mirror film)</td>
<td>20.7 20.7 20.7 17.2 3.4</td>
<td>3.4 10.3</td>
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<td>20d - Introduce dynamic insulation devices: (<em>Beadwall</em>, blinds, roll-up shades)</td>
<td>10.3 3.4 34.5 24.1 13.8</td>
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<tr>
<td>21 - NATURAL VENTILATION</td>
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<tr>
<td>21a - Operable windows</td>
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<tr>
<td>21b - Ventilation through window frame</td>
<td>10.3 13.8 10.3 13.8 17.2 13.8</td>
<td>13.8 6.9</td>
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<td>22 - COUNTERACT UNCOMFORTABLE MEAN RADIANT TEMPERATURE (near window)</td>
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<td>22a - Increase thermal storage capacity in edge zones (phase-change panels)</td>
<td>13.8 3.4 27.6 17.2 24.1</td>
<td>3.4 3.4 6.9</td>
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<tr>
<td>22b - Radiant floor or radiant ceiling</td>
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<td>3.4 6.9</td>
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<td>23 - WINDOWS AS COMPREHENSIVE ENVIRONMENT MODIFIERS</td>
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<td>23a - Reversible window with blinds on one side</td>
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<tr>
<td>23c - Automatic sensors and controls with manual overrides</td>
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<td>3.4 10.3</td>
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<td>24 - IMPROVED PREFABRICATED INSULATING DECKS</td>
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<td>25 - CONTINUOUS ELASTIC ROOFING MEMBRANE</td>
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<td>INNOVATION</td>
<td>GREATEST IMPORTANCE</td>
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<td>25a-Single-ply continuous membranes</td>
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<td>26-Reduction of thermal shock on roof</td>
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<td>10.3</td>
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<tr>
<td>26b-Membrane through earth covering and planting</td>
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<tr>
<td>26c-Membrane through earth covering and planting</td>
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<td>27-Utilize roof as energy plant</td>
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<tr>
<td>27b-Wind generators, etc.</td>
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<tr>
<td>27c-Wind generators, etc.</td>
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<td>28-Reduced solar load on roof</td>
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<tr>
<td>28a-High parapets, roof-mounted shading devices</td>
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<td>28b-High parapets, roof-mounted shading devices</td>
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<tr>
<td>28c-High parapets, roof-mounted shading devices</td>
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<tr>
<td>28d-High parapets, roof-mounted shading devices</td>
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Table A4. Estimates of Importance of Enclosure Innovations (Cont.)
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<thead>
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<th>INNOVATION</th>
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<tr>
<td>1 -STIFFNESS IN HIGHRISE BUILDINGS</td>
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<td>1a-Frame-truss combination; Outrigger truss; &quot;Tie-down&quot; truss</td>
<td>33.3 : 8.3 : 25.0 : 16.7 : 16.7</td>
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<td>1d-Tubular structures</td>
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<td>3 -WIND RESISTANT DESIGN</td>
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<tr>
<td>3a-Aerodynamically stable building forms</td>
<td>36.4 : 27.3 : 27.3 : 9.0</td>
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<td>4 -SEISMIC DESIGN</td>
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<tr>
<td>4d-For very large bldgs, ensure appropriate dimensions or seismic subdiv</td>
<td>16.7 : 33.3 : 33.3 : 16.7</td>
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<td>6 -MATERIAL DEVELOPMENT</td>
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<tr>
<td>6a-Light-weight, high-strength, reinforced concrete</td>
<td>46.2 : 7.7 : 7.7 : 38.4</td>
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<tr>
<td>7 -FOUNDATIONS</td>
<td></td>
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<tr>
<td>7b-Preconsolidation</td>
<td>50.0 : 25.0 : 12.5</td>
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<tr>
<td>8 -COMPOSITE STRUCTURE</td>
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<tr>
<td>10 -FIRE PROTECTION</td>
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<td>10b-Fire resisting paint</td>
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Table A5. Benefits of Selected Structural Innovations (Cont.)

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<td>12a-Lightweight alloys</td>
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<td><strong>13</strong> - FLEXIBLE SERVICES</td>
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<td>13a-Interstitial space</td>
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<td><strong>14</strong> - PREFABRICATION/INDUSTRIALIZATION</td>
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<tr>
<td>14a-Large scale prefabricated-pre-finished structural elements</td>
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<tr>
<td>14b-Large scale facade elements</td>
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<tr>
<td>14e-Post tensioning</td>
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<td>14h-Computer-aided construction</td>
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Table A6. Constraints of Selected Structural Innovations

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<td>1a-Frame-truss combination; Outrigger truss; &quot;Tie-down&quot; truss</td>
<td>50.0 : 25.0 : 25.0</td>
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<td>1b-Tubular structures</td>
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<td>3 - WIND RESISTANT DESIGN</td>
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<td>3a-Aerodynamically stable building forms</td>
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<td>4 - SEISMIC DESIGN</td>
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<td>4a-For very large blds, ensure appropriate dimensions or seismic subdiv</td>
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<td>6 - MATERIAL DEVELOPMENT</td>
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<td>6a-Light-weight, high-strength, reinforced concrete</td>
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<td>7 - FOUNDATIONS</td>
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<tr>
<td>7b-Preconsolidation</td>
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<td>8 - COMPOSITE STRUCTURE</td>
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<td>8c-Steel and reinforced concrete construction</td>
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<td>10 - FIRE PROTECTION</td>
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<tr>
<td>10b-Fire resisting paint</td>
<td>37.5 : 12.5 : 12.5 : 12.5 : 12.5</td>
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<td>CONSTRAINTS</td>
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<tr>
<td>12 - MASS REDUCTION AND INCREASED DUCTILITY</td>
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<tr>
<td>12a - Lightweight alloys</td>
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<td>13 - FLEXIBLE SERVICES</td>
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<td>14 - PREFabrication/INDUSTRIALIZATION</td>
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<tr>
<td>14a - Large scale prefabricated-pre-finished structural elements</td>
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<td>14b - Large scale facade elements</td>
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<tr>
<td>14e - Post tensioning</td>
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<td>14h - Computer-aided construction</td>
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Table A7. Benefits of Selected Enclosure Innovations

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<td>3d-Thermal modelling in design</td>
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<td>4 - REDUCE HIGH-WIND EFFECTS</td>
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<tr>
<td>4a-Wind resistant design</td>
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<td>5 - MINIMIZE RAINWATER PENETRATION THROUGH JOINTS</td>
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<tr>
<td>5b-Water tighten joints</td>
<td>71.4 : 28.6</td>
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<td>9 - USE OF COMPOSITE MATERIALS</td>
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<td>9b-Glass fiber reinforced concrete cladding</td>
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<td>10 - USE OF PREFAB MASS WALLS</td>
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<tr>
<td>10b-PreCast concrete wall component</td>
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<td>11a-Sandwich panel systems</td>
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<td>14b-Solar collectors</td>
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Table A8. Constraints of Selected Enclosure Innovations

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<td>4 - REDUCE HIGH-WIND EFFECTS</td>
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<td>4a-Wind resistant design</td>
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<td>5 - MINIMIZE RAINWATER PENETRATION THROUGH JOINTS</td>
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<td>5b-Water tighten joints</td>
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<td>66.7</td>
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<td>9 - USE OF COMPOSITE MATERIALS</td>
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<td>9b-Glass fiber reinforced concrete cladding</td>
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<td>10b-Precast concrete wall component</td>
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<td>11a-Sandwich panel systems</td>
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<td>13a-Building geometry</td>
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<td>14 - CONSERVE OPERATIONAL ENERGY BY ACTIVE SYSTEMS</td>
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<td></td>
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<td>14b-Solar collectors</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
The following innovations were added by respondents:

1. Non-weatherproofed steel frames
2. Bundled tube structure
3. Partial tubular structural systems
4. Core-braced steel frame
5. Steel tubular system with exterior composite columns
6. Concrete admixture to eliminate shrinkage
7. Post-tensioned concrete raft foundations
8. Normal weight high strength concrete
9. Fiber glass reinforced concrete
10. Light weight steel truss composite design with concrete over metal deck
11. Seismic base isolation using lead-rubber bearings
12. Hydraulic shock absorbers
13. Two-way Vierendeel trusses (as megaframes) for gravity and seismic resistance of high-rise buildings
14. Interior steel plate shear walls
15. Coupled shear walls
16. Staggered trusses - where floor slabs span from top chord of one truss to bottom chord of adjacent truss
17. Two-way ribbed metal deck
18. Raised floor systems
19. "IRMA" (inverted roof membrane assembly)
20. Completely prefabricated insulating deck with roof membrane and built-in vapor barrier
21. Reflective surface or protected membrane
22. Reduction of thermal shock and ultraviolet deterioration with insulation on top of roof membrane
23. Reduce solar load with steep sloping or folded plate self-shading roof
24. Integrated building systems
25. Pre-assembled floor segments
26. Skip-joist
27. Haunch girder
28. Tapered rolled beams
29. Below-grade connection of buildings
30. Inverted roofing with insulation exterior to membrane
31. Glass fiber concrete
APPENDIX C. Coding Manual
NBS SURVEY OF TECHNOLOGICAL INNOVATIONS
FOR OFFICE BUILDINGS

CODING MANUAL

Catherine Coburn

Stephen T. Margulis

We wish to thank Mary R. Speth and Andrew Gordon for assistance with the coding, and Mike Brill, Gunter Schmitz, and Tibor D. Scizmadia for serving as expert consultants

January 1984
THE CODING CATEGORIES

BOSTI coded the benefits and constraints mentioned by respondents for the innovations which they regarded as the most important. The coding categories are:

1. Cost 8. Weight/Height
2. Time 9. Efficiency
4. Design 11. New Materials Needed
5. Aesthetics 12. Training Needed
7. Quality 14. Other

The table below presents the range of application of each coding category: whether it applies to structural or enclosure system innovations or to both and whether it applies to benefits or constraints or to both.

THE RANGE OR APPLICATION OF THE TECHNOLOGICAL INNOVATIONS' CODING CATEGORIES

<table>
<thead>
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<th>Coding Categories</th>
<th>Structural and Enclosure Systems Innovations</th>
<th>Enclosure Systems Innovations Only</th>
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<td>BENEFITS ONLY</td>
<td>CONSTRAINTS ONLY</td>
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<td>CODING 1-6</td>
<td>7</td>
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<tr>
<td>CATEGORY 13</td>
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Coding categories that applied to both benefits and constraints were defined somewhat differently, depending on whether benefits or constraints were being coded. Therefore, for categories 1-6 and 13, which apply to both benefits and constraints, two definitions are listed. Unless otherwise noted, all coding categories apply to both the "Enclosure" and "Structure" questionnaires.
1. **Cost**

**Benefits** - These responses indicate that the innovation would reduce costs. Some respondents were more specific, citing, for example, reduced material costs and reduced construction costs. However, there were not enough of any of these specific comments to warrant separate categories.

It should be noted that unless we found at least ten instances of a potential category, a new category was not formed, and the statements were assigned to another category if possible or coded as "Other" (Category 15). As a case in point, we originally had a category called Reduced Material Needs, but there were very few instances (about 5) and, since almost all had an explicit cost implication, they were assigned to the Cost category.

**Constraints** - These answers indicate that the innovation would increase costs. Again, although some respondents were specific about the nature of the cost increase, there were not sufficient numbers of any one type to warrant separate coding categories.

2. **Time**

**Benefits** - These responses indicate that the proposed innovation would reduce the time needed for building completion. Occasionally, respondents were specific, mentioning time needed for construction most often, but once again, there were too few mentions of specific time-related benefits to warrant separate categories.

**Constraints** - These statements indicate that the proposed innovation would increase the time needed for building completion. There were two classes of specific answers: time needed for construction (most frequent) and time needed for building code approval.
3. **Structural Integrity**

**Benefits** - These answers stated that the proposed innovation would increase the building's strength, structural integrity or durability or that it would decrease the building's susceptibility to damage. For example, the following response to structural innovation 12b, Plastics, is typical of this category: "The use (of) plastics as structural elements could greatly increase strength and ductility...." Although concerns about strength, structural integrity and damage appeared in responses to both the structure and enclosure system innovations, "strength", as an issue, predominated in the structural system questionnaires and "damage" appeared as an issue somewhat more frequently in the Enclosure questionnaires.

**Constraints** - These responses stated that the proposed innovation would decrease the building's strength, structural integrity or durability or that it would increase the building's susceptibility to damage.

These responses more often addressed the issues of damage and durability than strength.

4. **Design**

**Benefits** - These responses stated that the innovation would improve the design of the building. The following response, to structural innovation 13a, Interstitial Space, is typical: "Prevents breaking of vertical continuity of work space."

**Constraints** - These statements indicate that the proposed innovation would restrict design options and/or result in a poorer design. This category also includes statements which indicate that implementation of the innovation would pose design problems. For example, to Structural Innovation 1a, Trusses, one respondent wrote: "The architectural design must include provisions for a clean and regular frame, truss structural system."

C-5
5. Aesthetics

**Benefits** - These responses indicate that the proposed innovation would improve the appearance of the resulting building in some way. Responses in this category cover a fairly wide range of issues, from the architectural compatibility of the proposed innovation with existing buildings, to the appearance of the interior of the building to its occupants. For example, in response to Enclosure innovation 11c, on glass walls, the respondent wrote: "The use of glass in office buildings is important for providing visual contact with the outdoors, and for natural light...."

**Constraints** - This category includes responses which stated that the innovation would result in a less attractive building. As with benefits, there was a fairly wide range of responses. However, the most frequent response in this category was the single word "appearance."

6. Construction

**Benefits** - These responses state that the innovation would increase the ease of construction. There was very little variation in the responses in this category; virtually all of them used the phrase "ease of construction." Only a few respondents elaborated.

**Constraints** - These responses state that the innovation would increase the difficulty of construction. As with the construction benefits, there was relatively little variation in answers.

7. Quality

**Benefits** - These responses stated, without elaboration, that the overall quality of the resulting building would be improved by the implementation of the proposed innovation. Many of these responses were very brief, often consisting of only the single word "quality." This category also included responses which cite increased quality control as a benefit of the proposed innovation. These responses are included here, rather than in a separate category, because there were too few of them to warrant a separate category.
8. Reduced Benefits - These responses indicate that the proposed innovation would reduce the weight of the resulting building. One respondent indicated that the innovation would reduce the height of the resulting building and it is included in this category.

9. Efficiency - These statements indicate, without elaboration, that the proposed innovation is "efficient." As in the case of Category 7 (Quality), the responses were usually brief and often consisted of the single word "efficient." Answers which specified the nature of the efficiency in some way (e.g. "efficient means of conserving energy") were coded according to the specifics of the answer.

10. Research Needed - These statements indicate that further research is necessary to ensure the safety, effectiveness, etc. of the innovation. Answers which specified the high cost of research were coded as Cost Constraints. (See "Coding Procedures" for a discussion of how coding categories were applied.)

11. New Materials or Procedures - These statements specify the need for the development of new materials or procedures in order to permit or facilitate the implementation of the innovation. The following response is typical of this category: "Present admixtures used to control shrinkage are not foolproof and consistent."

12. Personnel/Training - The responses in this category specifically address the need for specially trained personnel and/or educational programs in order for the implementation of the innovation to take place. There were a few answers which mentioned the need for high quality workmanship and these were also included in this category as being illustrative of a personnel or training issue.

C-7
13. Acceptance

**Benefits** - These statements indicate that the proposed innovation is already well-accepted by architects, owners and/or others. This category also includes statements indicating that the innovation has already "proved itself" (i.e., it is already in use).

**Constraints** - These statements indicate that the proposed innovation is expected to be resisted by architects, owners, users or others. Some respondents were more specific (e.g. citing resistance based on cost, appearance, etc.), but these were too infrequent to warrant separate categories.

15. Other

[See end of listing.]

20. Energy Conservation

**Benefits** - These responses specifically claimed that the innovation was or would be an effective means of conserving energy or preventing heat loss.

15. Other

This category uses the same definition for benefits and constraints. It includes benefits and constraints which do not fit into the other coding categories and which are too infrequent to warrant the creation of separate categories. Topics include logistics (whether or not materials are available on site), anticipated difficulties in getting building code approval, etc.

**CODING PROCEDURES**

**Definition of the units to be coded**

For each innovation for which there were benefits or constraints, the first two codable responses were coded, if more than one response was listed. The majority of the respondents had at least one innovation for which they gave two or more benefits or constraints.
In determining what constituted a single benefit or constraint, when more than one was present, the coders used syntax and punctuation as guides. Single words which were clearly not part of a sentence, and short phrases followed by periods, were treated as complete statements for coding purposes. In the case of longer sentences, coders treated simple sentences as single statements. For complex sentences, clauses within a sentence which contained new, codeable information were treated as single statements.

Applying the Coding Categories

Single statements (as defined above) for a specific respondent and innovation were never assigned to more than one coding category. In determining which coding category to use for statements that might reasonably receive multiple codes, the coders determined the "main point" of the statement and only the main point was coded. For example, the phrase "research costs," in principle, could be coded either as "Cost" or as "Research Needed." However, the main point of the phrase is cost, with "research" serving as a modifier of "cost." To give a second example, "Architects dislike the aesthetics" could be coded as either "Acceptance" or "Aesthetics." It would, however, be coded as Acceptance, since the main point or emphasis of the sentence is on the dislike or resistance rather than on what is disliked. For a specific respondent and innovation, if two benefits or two constraints were mentioned, then the same coding category was not assigned to the two benefits or the two constraints. So, for example, if a person mentioned overall cost and research costs as the benefits of the same innovation, "cost" would be assigned only once.

Uncoded Statements

Whenever possible, we assigned statements made by respondents to coding categories. However, it was necessary in some cases to leave statements uncoded. There were several reasons for this.

1. We limited the respondents to discussing 10 innovations. In some cases, more than 10 were discussed. In these cases, the first 10 innovations were coded and the remainder was left uncoded.
2. We coded only two Benefits or Constraints per innovation per respondent. When more than two were listed, we again coded the first two codable ones to occur, and left the remainder uncoded. For example, if the first several responses were uncodable, then the first two codable ones would be sought.

3. In order to be coded, a response had to be clearly a benefit or constraint. Repetitions of the innovation and vague, general statements (e.g. "this innovation is important") were not coded.

4. The response had to be clearly linked to a specific innovation. Thus, if a respondent chose to comment generally on the innovations as a group, without specifying an innovation or its identification number, the information was not coded.

5. The response had to be legible and interpretable. In a very few cases, respondents produced illegible or uninterpretable answers. The latter included: statements of benefits when constraints were required, and vice versa; and answers which the coders could not interpret. As an example of the latter, one respondent simply wrote the single word "do" as a benefit of an innovation. This might have meant that the innovation should be implemented, but even if we could be sure of this interpretation, this answer would fall outside of our coding categories and still could not be coded.

Appendix 1 of this manual lists the identification numbers of respondents who produced uncoded information. The list is divided into three categories:

1. Uncoded information along with a coded answer (i.e. more than two codable benefits or constraints listed for one innovation).

2. No innovation number and/or more than 10 innovations discussed.

3. Illegible or uninterpretable.

It should be noted that, with the exception of a few respondents who provided no innovation numbers, virtually all of the listed respondents produced at least some coded information.
Coder Familiarization, Reliability, and Coding Procedures

The coding categories for Benefits and Constraints were created by one of three coders and were based on an intensive examination of all the responses in the questionnaires. After all the coders reviewed the questionnaires and the initial set of categories had been established, all three coders discussed the categories and suggested modifications and additions. When the coding categories were established, the questionnaires were coded by the three coders, working independently. One coder covered the Structure questionnaires and the other two worked on equal numbers of the Enclosure questionnaires.

No formal test of coder reliability was conducted. In lieu of that, two of the coders jointly reviewed all of the questionnaires to check for errors. Differences in interpretation (between the two coders doing the review and/or between one of the coders doing the review and the code written down for a statement) were resolved by the two coders. During the review phase, the reviewers also made a few minor revisions in the coding system. One category, Reduced Material Needs, was eliminated as a separate category because there were too few responses. These responses were recoded as "Cost" since virtually all of the answers had cost implications. Category 6, Construction, was added at this time, and Category 13, Acceptance, which was originally used for constraints only was broadened to include benefits as well. Finally, possible coding problems arising from the meaning of technical terms used by the respondents were resolved with the help of a technical expert.

Evaluating the Innovations Added by the Respondents

Respondents, as experts, were given the option of adding innovations to those listed in each questionnaire. Two technical experts evaluated all of the added innovations and decided which were reasonable additions and which were not. The reasonable additions were made part of the data file.

The questionnaires with additional innovations indicate, either on the cover sheet or on the page with the additional innovations, whether each added innovation was approved or rejected for inclusion in the data file. Appendix 3 lists the respondents who had reasonable additional innovations.
Because there were so few added innovations, they were *not* assigned separate identification codes. Therefore, all of the first listed added innovations are coded with the same identification number, and so on.
Office Building Structures and Enclosures: A Survey of Experts

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NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
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Public Buildings Service
General Services Administration
Washington, DC 20405

This report presents the results of a study undertaken to identify probable trends affecting the form/design, materials and construction technologies of future office buildings. A literature review was conducted that addressed emerging technologies for structural systems and exterior enclosures of office buildings. Issues identified in the review were used to develop questionnaires for surveying expert opinions about technological innovations. Experts estimated the availability and importance of various structural and enclosure innovations, and provided their perceptions of the benefits and constraints of up to 10 innovations of their choosing.

Buildings; construction; design; enclosures; materials; structural engineering.

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