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Innovative Office Building Structures and Enclosures:

A Survey of Experts

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INNOVATIVE OFFICE BUILDING STRUCTURES AND ENCLOSURES: A SURVEY OF EXPERTS

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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/precast 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.

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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 stuctural 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 reponse 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/precast 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 continous 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

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2. Schön, D. A., "Forecasting and Technological Forecasting". Daedalus, 1967, 69(3), (759-770).

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

	GROUP 1 (Innovation selected for discussion)						GROUP 2 (Innovation not selected for discussion)					
IMPORTANCE SCALE POSITIONS	INNOVATION 1a	1d	3a	6a	12a	TOTAL	INNOVATION 1a	1d	3a	6a	12a	TOTAL
0							3	2	1		1	7 (7.4%)
1									1		2	3 (3.2%)
2							1					1 (1.1%)
3							1				1	2 (2.1%)
4							1	2		1	2	6 (6.3%)
5	1					1 (2.2%)	5	2	3	2	2	14 (14.7%)
6							1	2	4	2	4	13 (13.7%)
7	3		1	1		5 (10.9%)	4	3	3	1	1	12 (12.6%)
8	1	2	1	2	2	8 (17.4%)	1	1	4	4	2	12 (12.6%)
9	2	11	7	6	6	32 (69.5%)	2	7	3	9	4	25 (26.3%)
						46 (100%)						95 (100%)

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

INNOVATIONS	AVAILABILITY (%)			IMPORTANCE (%)		
	By 1985	5-10 years	Long-term or never	Major	Moderate	Minor
1 STIFFNESS IN HIGHRISE BUILDINGS						
a Frame-truss combination; Outrigger truss; "Tie-down" truss	76				59	
b Exterior steel plate shear walls	46					51
c Inclined or pyramid-shaped frame	67				46	
d Tubular structures	90			54		
2 VERTICAL FLEXIBILITY						
a Megaframes		42			53	
b Hollow tubular buildings	50			37	36	
c Exterior shafts	53				51	
d Vertically curved or folded plate walls as support		40				51
3 WIND RESISTANT DESIGN						
a Aerodynamically stable building forms	44			49		
b Drag reduction		38			49	
4 SEISMIC DESIGN						
a Y-shape box columns		50			56	
b Eliminate "soft storey"	63				46	
c Shear walls graduated by height	79				46	

Table 2. Summary of Availability and Importance of Structural Innovations (Cont.)

INNOVATIONS		AVAILABILITY (%)			IMPORTANCE (%)		
		By 1985	5-10 years	Long-term or never	Major	Moderate	Minor
d	For very large bldgs, ensure appropriate dimensions or seismic subdiv.	69			49		
e	Ensure vertical continuity or seismic separation at setbacks	58			44	44	
f	Eccentric braced frames	66				49	
g	Flexible sliding foundation			45			44
5	<u>STRUCTURAL DAMPING</u>						
a	Active damping	41					39
b	Visco-elastic damping		49			46	
c	Damping friction at bolted connections		39			51	
6	<u>MATERIAL DEVELOPMENT</u>						
a	Light-weight, high-strength, reinforced concrete	55			73		
7	<u>FOUNDATIONS</u>						
a	Mixed-in-place stabilizers	60				46	
b	Preconsolidation	84				42	
c	Reinforced earth	64				51	
8	<u>COMPOSITE STRUCTURE</u>						
a	concrete exterior, steel interior frame	82				46	
b	Steel plate cladding bonded to concrete members	42				61	

Table 2. Summary of Availability and Importance of Structural Innovations (Cont.)

INNOVATIONS		AVAILABILITY (%)			IMPORTANCE (%)		
		By 1985	5-10 years	Long-term or never	Major	Moderate	Minor
c	Steel and reinforced concrete construction	95			71		
9	EXTERIOR FINISH						
a	Controlled rust steel or stainless steel	66				49	
10	FIRE PROTECTION						
a	Water cooled structural membranes	45					54
b	Fire resisting paint		42				73
11	RELOCATABLE BUILDINGS						
a	Unit construction or modular space frame	54				49	
b	Plastic "umbrella"		51				54
c	Suspension cable structure	69				39	
d	Fabric structure	69				51	
12	MASS REDUCTION AND INCREASED DUCTILITY						
a	Lightweight alloys		45			44	
b	Plastics			51		42	
c	Tension structures	58				59	
13	FLEXIBLE SERVICES						
a	Interstitial space	74				51	
b	Exterior shafts, ducts	65				54	

Table 2. Summary of Availability and Importance of Structural Innovations (Cont.)

INNOVATIONS	AVAILABILITY (%)			IMPORTANCE (%)		
	By 1985	5-10 years	Long-term or never	Major	Moderate	Minor
14 PREFABRICATION/INDUSTRIALIZATION						
a Large scale prefabricated-prefinished structural elements	54			49		
b Large scale facade elements	76			46	44	
c Industrialized systems	72			46	44	
d Prefab space modules	62				56	
e Post tensioning	93			54		
f Composite steel/precast concrete structural systems	83			46	44	
g Robotics		53			46	
h Computer-aided construction		46		58		
i Fabric structures	56				51	

Table 3. Summary of Availability and Importance of Enclosure Innovations

INNOVATIONS	AVAILABILITY (%)			IMPORTANCE (%)		
	By 1985	5-10 years	Long-term or never	Major	Moderate	Minor
1 INTER-BUILDING CIRCULATION AND CLIMATIC BUFFER ZONES						
a Pedestrian bridges (skyways) and clip-on corridors	82					41
b Enclosing space between buildings	68				45	
c Solaria (designed in or clip-on)	50					45
d Super-envelope over a group of buildings			68			48
2 NEW MATERIALS WHICH ALTER ENCLOSURE FORMS						
a Modern "permanent" fabric structures (cable re-strain, air support, etc.)	52				59	
3 SOPHISTICATED DESIGN/ EVALUATION PROCEDURES						
a Computer generated facades	44	44			48	
b Design using solar envelopes		48			69	
c Thermographic cameras to detect leaks	59				45	
d Thermal modeling in design		54		48		

Table 3. Summary of Availability and Importance of Enclosure Innovations (Cont.)

INNOVATIONS	AVAILABILITY (%)			IMPORTANCE (%)		
	By 1985	5-10 years	Long-term or never	Major	Moderate	Minor
4 REDUCE HIGH-WIND EFFECTS						
a Wind resistant design	61			45		
b "Roughen" perimeter surface with protrusions, setbacks, etc.	42					48
5 MINIMIZE RAINWATER PENETRATION THROUGH JOINTS						
a Reduce joints	63			41	41	
b Water tighten joints	61			73		
c Use rainscreen/decompression chamber/drained joint		52			59	
6 FACILITATE FUTURE FACADE CHANGES						
a Interchangeable components and access to building's exterior		50			66	
7 USE OF HOMOGENOUS, INORGANIC CELLULAR MATERIALS						
a Cellular or foamed glass		61			55	
b Cellular or aerated concrete		74			55	
c Foamed ceramic bricks		81			62	
8 USE OF THERMAL INSULATION MATERIALS FOR EXTREME OUTSIDE OF EXTERIOR WALL						
a External insulation	52			41		

Table 3. Summary of Availability and Importance of Enclosure Innovations (Cont.)

INNOVATIONS	AVAILABILITY (%)			IMPORTANCE (%)		
	By 1985	5-10 years	Long-term or never	Major	Moderate	Minor
b Surface coated porous fire clay		67			66	
c Insulating ceramic tiles		63			66	
9 USE OF COMPOSITE MATERIALS						
a Surface impregnated cellular concrete		68			69	
b Glass fiber reinforced concrete cladding	52				52	
c Integrated wall panel construction systems	81			45		
10 USE OF PREFAB MASS WALLS						
a Prefab brick wall component	82				45	
b Precast concrete wall component	100			52		
11 USE OF MINIMUM MASS SKIN COMPONENTS						
a Sandwich panel systems	89			55		
b Ultra-thin sandwich material		58			41	
c Tinted, heat-absorbing, reflective glass wall	78				62	
d Firestop glazing		57			55	

Table 3. Summary of Availability and Importance of Enclosure Innovations (Cont.)

INNOVATIONS		AVAILABILITY (%)			IMPORTANCE (%)		
		By 1985	5-10 years	Long-term or never	Major	Moderate	Minor
12	USE OF BUTT JOINT GLASS PANES (for continuous fenestration)						
a	Silicone glazing sealants	65				52	
13	CONSERVE OPERATIONAL ENERGY BY PASSIVE METHODS FOR MINIMIZING HEAT'G/COOL'G/LIGHT'G						
a	Building geometry	79			66		
b	Glazed area in wall	68				55	
c	Heat loss through joints	67				52	
d	Operable windows	79				48	
e	Air-to-air heat exchangers	67				55	
f	Thermal mass for natural cooling	56				48	
g	Trombe walls, solaria, atria, 2nd envelope		52			55	
14	CONSERVE OPERATIONAL ENERGY BY ACTIVE SYSTEMS						
a	Absorbers/heat pump	81			45	45	
b	Solar collectors	57			48		
c	Photovoltaic cells		54		45	45	
d	Sensors to automatically relate interior envir. to outside cond. for optimal energy management	54			66		

Table 3. Summary of Availability and Importance of Enclosure Innovations (Cont.)

INNOVATIONS	AVAILABILITY (%)			IMPORTANCE (%)		
	By 1985	5-10 years	Long-term or never	Major	Moderate	Minor
15 SUN CONTROL WITH EXTERIOR SHADING DEVICES						
a Improve overhangs	83			52		
b Use of vines and plants	78				38	
c Use lightweight sun screen	75				48	
d Operable exterior venetian blinds	58					42
e Adjustable exterior louvers	65				52	
f Fabric shades, awnings	93					42
g Solar shutters(panels or rolling)		46			55	
16 SUN CONTROL WITH INTERIOR SHADING DEVICE						
a Improved curtain material	73				45	
b Rollshades (tightly sealing)	63				55	
c Vinyl-coated fabric (semi-transparent or translucent)	56				62	
d Reflective synthetic films	71				52	
e Adjustable louvers, blinds	93				52	

Table 3. Summary of Availability and Importance of Enclosure Innovations (Cont.)

INNOVATIONS	AVAILABILITY (%)			IMPORTANCE (%)		
	By 1985	5-10 years	Long-term or never	Major	Moderate	Minor
17 SUN CONTROL IN WINDOW PLANE						
a Venetian blinds or shades between glass	67				65	
b Coated, absorbing, tinted glass	85				45	
c Spectrally selective glass		67			45	
d Optical shutter of thermally "opacifiable" glass		90			48	
e Photochromic glass		68			52	
f Solar control films with adhesive backing	64				45	
g Tilted window	80				41	
18 REFLECTION DEVICES TO BEAM DAYLIGHT INTO WORK ENVIRONMENT						
a Light shelves	58				45	
b Paired reflectors with tilted window	43				48	
c Adjustable horizontal blinds	74				52	
19 CONTROL AIR INFILTRATION/ EXFILTRATION						
a Increase air tightness	81			59		
b Reduce total length of joints	61			48		

Table 3. Summary of Availability and Importance of Enclosure Innovations (Cont.)

INNOVATIONS	AVAILABILITY (%)			IMPORTANCE (%)		
	By 1985	5-10 years	Long-term or never	Major	Moderate	Minor
20 IMPROVE INSULATION VALUE OF WINDOWS						
a Two parallel identical windows	72					38
b Improve frame (thermal breaks, rigid vinyl)	81				52	
c Improv glazing area (double panes w/Krypton gas,heated mirror film)	50			42		
d Introduce dynamic insulation devices ("Beadwall", blinds, roll-up shades)		56			72	
21 NATURAL VENTILATION						
a Operable windows	93			48		
b Ventilation through window frame	60				41	
22 COUNTERACT UNCOMFORTABLE MEAN RADIANT TEMPERATURE (near window)						
a Increase thermal storage capacity in edge zones.		67			69	
b Radiant floor or radiant ceiling	63				52	
23 WINDOWS AS COMPREHENSIVE ENVIRONMENT MODIFIERS						
a Reversible window with blinds on one side		48				52

Table 3. Summary of Availability and Importance of Enclosure Innovations (Cont.)

INNOVATIONS	AVAILABILITY (%)			IMPORTANCE (%)		
	By 1985	5-10 years	Long-term or never	Major	Moderate	Minor
b Multi-layer mechanized window		52			48	
c Automatic sensors and controls with manual overrides		64			48	
24 <u>IMPROVED PREFABRICATED INSULATING DECKS</u>	52			55		
25 <u>CONTINUOUS ELASTIC ROOFING MEMBRANES</u>						
a Single-ply continuous membranes	76			66		
26 <u>REDUCTION OF THERMAL SHOCK ON ROOF MEMBRANE</u>						
a Through earth covering and planting	59					45
27 <u>UTILIZE ROOF AS ENERGY PLANT</u>						
a Self-tracking solar concentrators		56			62	
b Wind generators, etc.		42			55	
28 <u>REDUCED SOLAR LOAD ON ROOF</u>						
a High parapets; roof-mounted shading devices	52				35	

Table 4. Summary of Innovations Considered to be of Major to Moderate Importance and of Significance to GSA/PBS

STRUCTURAL INNOVATIONS	ENCLOSURE INNOVATIONS
Innovations Available and Dependable No Later Than 1985	
o Tubular structures o Reduction or accommodation of wind and seismic forces o Use of lightweight, high-strength, reinforced concrete o Design of composite structures of steel and reinforced concrete construction o Large scale prefabricated-prefinished structural elements o Large scale facade elements o Composite steel/precast concrete structural systems o Post tensioning	o Minimizing rainwater penetration by reducing the number of joints in the enclosure o Prefab mass walls using precast wall components o Passive methods such as improved building geometry to minimize heating, cooling and lighting o Active sensor systems to automatically relate the interior environment to outside conditions and thus conserve operational energy o Sun control using improved roof overhangs o Control of air infiltration/exfiltration through increased air tightness o Improved prefabricated insulating decks o Use of single-ply continuous roofing membranes
Innovations Requiring Additional Research and Development Over Next 5 to 10 Years	
o Computer-aided construction o Megaframes to provide for vertical flexibility o Y-shape box columns in seismic design o Structural damping augmented by means of damping friction at bolted connections	o Thermal modeling in design o Photovoltaic cells for conserving operational energy
Selected Innovations Identified by Survey but not Included in Survey Questionnaires	
o Bundled tube structures o Concrete admixtures to eliminate shrinkage o Seismic base isolation using lead-rubber bearings o Preassembled floor segments	o Inverted roof membrane assemblies o Completely prefabricated insulating deck with roof membrane and built-in vapor barrier o Reduced solar load with steep sloping or folded plate self-shading roofs

APPENDIX A. Questionnaires

0	1					
1	2	3	4	5	6	7

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

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:

CATEGORIES	INNOVATIONS
1. Stiffness in Highrise Buildings	1a. Frame-truss combination; Outrigger truss; Tying shear truss to exterior columns with belt trusses ("tie-down" truss)
	1b. Exterior steel plate shear walls
	1c. Inclined or pyramid-shaped frame
	1d. Tubular structures
2. Vertical Flexibility (permitting floor height modification after a period of use)	2a. Megaframes (supporting "blocks" of floors)
	2b. Hollow tubular buildings
	2c. Exterior shafts
	2d. Vertically curved or folded plate walls as supports
3. Wind Resistant Design	3a. Aerodynamically stable building forms
	3b. Drag reduction (discharge air to leeward of building)
4. Seismic Design	4a. Y-shape box columns (in welded moment-resisting rigid steel frames, the use of welded Y-shaped box columns welded to girders.)
	4b. Eliminate "soft storey" through: Widen base; add columns; add bracing; energy dissipation
	4c. Shear walls graduated by height
	4d. For very large buildings, ensure appropriate dimensions, or make seismic subdivisions
	4e. At setbacks: Ensure vertical continuity or seismic separation at setbacks
	4f. Eccentric braced frames
	4g. Flexible sliding foundation to reduce seismic vibration.
5. Structural Damping (of ultra-high buildings)	5a. Active damping control (tuned mass damper)
	5b. Visco-elastic damping
	5c. Damping friction at bolted connections

CATEGORIES	INNOVATIONS
6. Material Development (where soils are weak or materials unavailable)	6a. Light weight, high strength reinforced concrete
7. Foundations	7a. Mixed-in-place stabilizers
	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.

[8-37]

DESCRIPTION OF INNOVATION	PROBLEM IT TRIES TO SOLVE

DESCRIPTION OF INNOVATION	PROBLEM IT TRIES TO SOLVE

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.

INNOVATION	WHEN AVAILABLE AND DEPENDABLE ENOUGH.... ALREADY AVAILABLE, DEPENDABLE	BY 1985	BY 1990	BY 1995	LATER THAN 1995	NEVER	
1. STIFFNESS IN HIGHRISE BLDGS.							
1a. Frame-truss combination; Outrigger truss; "Tie-down" truss	1	2	3	4	5	6	[38]
1b. Exterior steel plate shear walls	1	2	3	4	5	6	[39]
1c. Inclined or pyramid-shaped frame	1	2	3	4	5	6	[40]
1d. Tubular structures	1	2	3	4	5	6	[41]
2. VERTICAL FLEXIBILITY							
2a. Megaframes	1	2	3	4	5	6	[42]
2b. Hollow tubular buildings	1	2	3	4	5	6	[43]
2c. Exterior shafts	1	2	3	4	5	6	[44]
2d. Vertically curved or folded plate walls as supports	1	2	3	4	5	6	[45]
3. WIND RESISTANT DESIGN							
3a. Aerodynamically stable building forms	1	2	3	4	5	6	[46]
3b. Drag reduction	1	2	3	4	5	6	[47]
4. SEISMIC DESIGN							
4a. Y-shape box columns	1	2	3	4	5	6	[48]
4b. Eliminate "soft storey"	1	2	3	4	5	6	[49]
4c. Shear walls graduated by height	1	2	3	4	5	6	[50]
4d. For very large buildings, ensure appropriate dimensions, or make seismic subdivisions	1	2	3	4	5	6	[51]
4e. Ensure vertical continuity or seismic separation at setbacks	1	2	3	4	5	6	[52]
4f. Eccentric braced frames	1	2	3	4	5	6	[53]
4g. Flexible sliding foundation	1	2	3	4	5	6	[54]

INNOVATION	WHEN AVAILABLE AND DEPENDABLE ENOUGH.... ALREADY AVAILABLE, DEPENDABLE	BY 1985	BY 1990	BY 1995	LATER THAN 1995	NEVER	
5. STRUCTURAL DAMPING							
5a. Active damping control	1	2	3	4	5	6	[55]
5b. Visco-elastic damping	1	2	3	4	5	6	[56]
5c. Damping friction at bolted connections	1	2	3	4	5	6	[57]
6. MATERIAL DEVELOPMENT							
6a. Light weight, high strength reinforced concrete	1	2	3	4	5	6	[58]
7. FOUNDATIONS							
7a. Mixed-in-place stabilizers	1	2	3	4	5	6	[59]
7b. Preconsolidation	1	2	3	4	5	6	[60]
7c. Reinforced earth	1	2	3	4	5	6	[61]
8. COMPOSITE STRUCTURE							
8a. Concrete exterior, steel interior frame	1	2	3	4	5	6	[62]
8b. Steel plate cladding bonded to concrete members	1	2	3	4	5	6	[63]
8c. Steel and reinforced concrete construction	1	2	3	4	5	6	[64]
9. EXTERIOR FINISH							
9a. Controlled rust steel or stainless steel	1	2	3	4	5	6	[65]
10. FIRE PROTECTION							
10a. Water cooled structural members	1	2	3	4	5	6	[66]
10b. Fire resisting paint	1	2	3	4	5	6	[67]
11. RELOCATABLE BUILDINGS							
11a. Unit construction or modular space frame	1	2	3	4	5	6	[68]
11b. Plastic "umbrella"	1	2	3	4	5	6	[69]
11c. Suspension cable structure	1	2	3	4	5	6	[70]
11d. Fabric structure	1	2	3	4	5	6	[71]

INNOVATION	WHEN AVAILABLE AND DEPENDABLE ENOUGH.... ALREADY AVAILABLE, DEPENDABLE	BY 1985	BY 1990	BY 1995	LATER THAN 1995	NEVER	
12. MASS REDUCTION AND INCREASED DUCTILITY							
12a. Lightweight alloys	1	2	3	4	5	6	[72]
12b. Plastics	1	2	3	4	5	6	[73]
12c. Tension Structures	1	2	3	4	5	6	[74]
13. FLEXIBLE SERVICES							
13a. Interstitial space	1	2	3	4	5	6	[75]
13b. Exterior shafts, ducts	1	2	3	4	5	6	[76]
							0 2
14. PREFABRICATION/INDUSTRIALIZATION							[1-2]
14a. Large scale prefabricated-prefinished structural elements	1	2	3	4	5	6	[3]
14b. Large scale facade elements	1	2	3	4	5	6	[4]
14c. Industrialized systems	1	2	3	4	5	6	[5]
14d. Prefab space modules	1	2	3	4	5	6	[6]
14e. Post tensioning	1	2	3	4	5	6	[7]
14f. Composite steel/precast concrete structural systems	1	2	3	4	5	6	[8]
14g. Robotics	1	2	3	4	5	6	[9]
14h. Computer-aided construction	1	2	3	4	5	6	[10]
14i. Fabric structures	1	2	3	4	5	6	[11]
15. OTHER ADDED INNOVATIONS							
15a. ____________	1	2	3	4	5	6	[12]
15b. ____________	1	2	3	4	5	6	[13]
15c. ____________	1	2	3	4	5	6	[14]
15d. ____________	1	2	3	4	5	6	[15]
15e. ____________	1	2	3	4	5	6	[16]
15f. ____________	1	2	3	4	5	6	[17]
15g. ____________	1	2	3	4	5	6	[18]
15h. ____________	1	2	3	4	5	6	[19]
15i. ____________	1	2	3	4	5	6	[20]
15j. ____________	1	2	3	4	5	6	[21]

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.]

INNOVATION	IT IS OF THE GREATEST IMPORTANCE									IT IS OF MINOR IMPORTANCE	
1. STIFFNESS IN HIGHRISE BLDGS.											
1a. Frame-truss combination; Outrigger truss; "Tie-down" truss	9	8	7	6	5	4	3	2	1	0	[22]
1b. Exterior steel plate shear walls	9	8	7	6	5	4	3	2	1	0	[23]
1c. Inclined or pyramid-shaped frame	9	8	7	6	5	4	3	2	1	0	[24]
1d. Tubular structures	9	8	7	6	5	4	3	2	1	0	[25]
2. VERTICAL FLEXIBILITY											
2a. Megaframes	9	8	7	6	5	4	3	2	1	0	[26]
2b. Hollow tubular buildings	9	8	7	6	5	4	3	2	1	0	[27]
2c. Exterior shafts	9	8	7	6	5	4	3	2	1	0	[28]
2d. Vertically curved or folded plate walls as supports	9	8	7	6	5	4	3	2	1	0	[29]
3. WIND RESISTANT DESIGN											
3a. Aerodynamically stable building forms	9	8	7	6	5	4	3	2	1	0	[30]
3b. Drag reduction	9	8	7	6	5	4	3	2	1	0	[31]

INNOVATION	IT IS OF THE GREATEST IMPORTANCE									IT IS OF MINOR IMPORTANCE	
4. SEISMIC DESIGN											
4a. Y-shape box columns	9	8	7	6	5	4	3	2	1	0	[32]
4b. Eliminate "soft storey"	9	8	7	6	5	4	3	2	1	0	[33]
4c. Shear walls graduated by height	9	8	7	6	5	4	3	2	1	0	[34]
4d. For very large buildings, ensure appropriate dimensions, or make seismic subdivisions	9	8	7	6	5	4	3	2	1	0	[35]
4e. Ensure vertical continuity <u>or</u> seismic separation at setbacks	9	8	7	6	5	4	3	2	1	0	[36]
4f. Eccentric braced frames	9	8	7	6	5	4	3	2	1	0	[37]
4g. Flexible sliding foundation	9	8	7	6	5	4	3	2	1	0	[38]
5. STRUCTURAL DAMPING											
5a. Active damping control	9	8	7	6	5	4	3	2	1	0	[39]
5b. Visco-elastic damping	9	8	7	6	5	4	3	2	1	0	[40]
5c. Damping friction at bolted connections	9	8	7	6	5	4	3	2	1	0	[41]
6. MATERIAL DEVELOPMENT											
6a. Light weight, high strength reinforced concrete	9	8	7	6	5	4	3	2	1	0	[42]
7. FOUNDATIONS											
7a. Mixed-in-place stabilizers	9	8	7	6	5	4	3	2	1	0	[43]
7b. Preconsolidation	9	8	7	6	5	4	3	2	1	0	[44]
7c. Reinforced earth	9	8	7	6	5	4	3	2	1	0	[45]
8. COMPOSITE STRUCTURE											
8a. Concrete exterior, steel interior frame	9	8	7	6	5	4	3	2	1	0	[46]
8b. Steel plate cladding bonded to concrete members	9	8	7	6	5	4	3	2	1	0	[47]
8c. Steel and reinforced concrete construction	9	8	7	6	5	4	3	2	1	0	[48]

INNOVATION	IT IS OF THE GREATEST IMPORTANCE									IT IS OF MINOR IMPORTANCE	
9. EXTERIOR FINISH											
9a. Controlled rust steel or stainless steel	9	8	7	6	5	4	3	2	1	0	[49]
10. FIRE PROTECTION											
10a. Water cooled structural members	9	8	7	6	5	4	3	2	1	0	[50]
10b. Fire resisting paint	9	8	7	6	5	4	3	2	1	0	[51]
11. RELOCATABLE BUILDINGS											
11a. Unit construction or modular space frame	9	8	7	6	5	4	3	2	1	0	[52]
11b. Plastic "umbrella"	9	8	7	6	5	4	3	2	1	0	[53]
11c. Suspension cable structure	9	8	7	6	5	4	3	2	1	0	[54]
11d. Fabric structure	9	8	7	6	5	4	3	2	1	0	[55]
12. MASS REDUCTION AND INCREASED DUCTILITY											
12a. Lightweight alloys	9	8	7	6	5	4	3	2	1	0	[56]
12b. Plastics	9	8	7	6	5	4	3	2	1	0	[57]
12c. Tension Structures	9	8	7	6	5	4	3	2	1	0	[58]
13. FLEXIBLE SERVICES											
13a. Interstitial space	9	8	7	6	5	4	3	2	1	0	[59]
13b. Exterior shafts, ducts	9	8	7	6	5	4	3	2	1	0	[60]
14. PREFABRICATION/INDUSTRIALIZATION											
14a. Large scale prefabricated-prefinished structural elements	9	8	7	6	5	4	3	2	1	0	[61]
14b. Large scale facade elements	9	8	7	6	5	4	3	2	1	0	[62]
14c. Industrialized systems	9	8	7	6	5	4	3	2	1	0	[63]
14d. Prefab space modules	9	8	7	6	5	4	3	2	1	0	[64]
14e. Post tensioning	9	8	7	6	5	4	3	2	1	0	[65]
14f. Composite steel/precast concrete structural systems	9	8	7	6	5	4	3	2	1	0	[66]
14g. Robotics	9	8	7	6	5	4	3	2	1	0	[67]
14h. Computer-aided construction	9	8	7	6	5	4	3	2	1	0	[68]
14i. Fabric structures	9	8	7	6	5	4	3	2	1	0	[69]

INNOVATION	IT IS OF THE GREATEST IMPORTANCE									IT IS OF MINOR IMPORTANCE	
15. OTHER ADDED INNOVATIONS											
15a. ______	9	8	7	6	5	4	3	2	1	0	[70]
15b. ______	9	8	7	6	5	4	3	2	1	0	[71]
15c. ______	9	8	7	6	5	4	3	2	1	0	[72]
15d. ______	9	8	7	6	5	4	3	2	1	0	[73]
15e. ______	9	8	7	6	5	4	3	2	1	0	[74]
15f. ______	9	8	7	6	5	4	3	2	1	0	[75]
15g. ______	9	8	7	6	5	4	3	2	1	0	[76]
15h. ______	9	8	7	6	5	4	3	2	1	0	[77]
15i. ______	9	8	7	6	5	4	3	2	1	0	[78]
15j. ______	9	8	7	6	5	4	3	2	1	0	[79]

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".

CARDS 3,4,5

INNOVATION	MAJOR BENEFITS

INNOVATION	MAJOR BENEFITS

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".

CARDS 6,7,8

INNOVATION	MAJOR CONSTRAINTS

INNOVATION	MAJOR CONSTRAINTS

0	1					
1	2	3	4	5	6	7

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.

CATEGORIES	INNOVATIONS
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
2. NEW MATERIALS WHICH ALTER ENCLOSURE FORMS	2a. Modern, "permanent" fabric structures (cable restrained, air supported structures and tensioned fabric structures)
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
EXTERIOR WALL	
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. Celullar 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

CATEGORIES	INNOVATIONS
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 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

CATEGORIES	INNOVATIONS
15. SUN CONTROL WITH EXTERIOR SHADING DEVICES	15a. Improved overhangs 15b. Use of vines and plants 15c. Use lightweight sun screen 15d. Operable exterior venetian blinds 15e. Adjustable exterior louvers 15f. Fabric shades, awnings 15g. Solar shutters (panels or rolling)
16. SUN CONTROL WITH INTERIOR SHADING DEVICES	16a. Improved curtain material 16b. Rollshades (tightly sealing) 16c. Vinyl-coated fabric (semi-transparent or translucent) 16d. Reflective synthetic films 16e. Adjustable louvers, blinds
17. SUN CONTROL IN WINDOW PLANE	17a. Venetian blinds or shades between glass 17b. Coated, absorbing, tinted glass 17c. Spectrally selective glass 17d. Optical shutter of thermally "opacifiable" glass 17e. Photochromic glass 17f. Solar control films with adhesive backing 17g. Tilted window
18. REFLECTION DEVICES TO BEAM DAYLIGHT INTO WORK ENVIRONMENT	18a. Light shelves 18b. Paired reflectors with tilted window 18c. Adjustable horizontal blinds
19. CONTROL AIR INFILTRATION/ EXFILTRATION	19a. Increase air tightness 19b. Reduce total length of joints

CATEGORIES	INNOVATIONS
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
<u>ABOUT ROOFS AND ROOFING</u>	
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.

[8-37]

DESCRIPTION OF INNOVATION	PROBLEM IT TRIES TO SOLVE

DESCRIPTION OF INNOVATION PROBLEM IT TRIES TO SOLVE

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.

INNOVATION	WHEN AVAILABLE AND DEPENDABLE ENOUGH.... ALREADY AVAILABLE, DEPENDABLE	BY 1985	BY 1990	BY 1995	LATER THAN 1995	NEVER	
ABOUT OVERALL EXTERIOR ENCLOSURE:							
1. INTER-BUILDING CIRCULATION AND CLIMATIC BUFFER ZONES							
1a. Pedestrian bridges (skyways) and clip-on corridors	1	2	3	4	5	6	[38]
1b. Enclosing space between buildings	1	2	3	4	5	6	[39]
1c. Solaria (designed in or clip-on)	1	2	3	4	5	6	[40]
1d. Super-envelope over a group of buildings	1	2	3	4	5	6	[41]
2. NEW MATERIALS WHICH ALTER ENCLOSURE FORMS							
2a. Modern, "permanent" fabric structures (cable restrained, air supported structures and tensioned fabric structures)	1	2	3	4	5	6	[42]
3. SOPHISTICATED DESIGN/ EVALUATION PROCEDURES							
3a. Computer generated facades	1	2	3	4	5	6	[43]
3b. Design using solar envelopes	1	2	3	4	5	6	[44]
3c. Thermographic cameras to detect leaks	1	2	3	4	5	6	[45]
3d. Thermal modelling in design	1	2	3	4	5	6	[46]

INNOVATION	ALREADY AVAILABLE, DEPENDABLE	BY 1985	BY 1990	BY 1995	LATER THAN 1995	NEVER	
	WHEN AVAILABLE AND DEPENDABLE ENOUGH....						
EXTERIOR WALL							
4. REDUCE HIGH-WIND EFFECTS							
4a. Wind resistant design	1	2	3	4	5	6	[47]
4b. "Roughen" perimeter surface with protrusions, setbacks, etc.	1	2	3	4	5	6	[48]
5. MINIMIZE RAINWATER PENETRATION THROUGH JOINTS							
5a. Reduce joints	1	2	3	4	5	6	[49]
5b. Water tighten joints	1	2	3	4	5	6	[50]
5c. Use rainscreen/decompression chamber/drained joint	1	2	3	4	5	6	[51]
6. FACILITATE FUTURE FACADE CHANGES							
6a. Interchangeable components and access to building's exterior	1	2	3	4	5	6	[52]
7. USE OF HOMOGENOUS, INORGANIC CELLULAR MATERIALS							
7a. Cellular or foamed glass	1	2	3	4	5	6	[53]
7b. Cellular or aerated concrete	1	2	3	4	5	6	[54]
7c. Foamed ceramic bricks	1	2	3	4	5	6	[55]
8. USE OF THERMAL INSULATION MATERIALS FOR EXTREME OUTSIDE OF EXTERIOR WALL							
8a. External insulation	1	2	3	4	5	6	[56]
8b. Surface coated porous fired clay	1	2	3	4	5	6	[57]
8c. Insulating ceramic tiles	1	2	3	4	5	6	[58]

INNOVATION	ALREADY AVAILABLE, DEPENDABLE	BY 1985	BY 1990	BY 1995	LATER THAN 1995	NEVER	
	WHEN AVAILABLE AND DEPENDABLE ENOUGH....						
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]

INNOVATION	WHEN AVAILABLE AND DEPENDABLE ENOUGH.... ALREADY AVAILABLE, DEPENDABLE	BY 1985	BY 1990	BY 1995	LATER THAN 1995	NEVER	
14. CONSERVE OPERATIONAL ENERGY BY ACTIVE SYSTEMS							
14a. Absorbers/heat pump	1	2	3	4	5	6	[76]
14b. Solar collectors	1	2	3	4	5	6	[77]
14c. Photovoltaic cells	1	2	3	4	5	6	[78]
14d. Sensors to automatically relate interior environmental control systems to outside conditions for optimal energy management	1	2	3	4	5	6	[79]

0	2

[1-2]

INNOVATION	ALREADY AVAILABLE, DEPENDABLE	BY 1985	BY 1990	BY 1995	LATER THAN 1995	NEVER	
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]

INNOVATION	WHEN AVAILABLE AND DEPENDABLE ENOUGH.... ALREADY AVAILABLE, DEPENDABLE	BY 1985	BY 1990	BY 1995	LATER THAN 1995	NEVER	
17. SUN CONTROL IN WINDOW PLANE							
17a. Venetian blinds or shades between glass	1	2	3	4	5	6	[15]
17b. Coated, absorbing, tinted glass	1	2	3	4	5	6	[16]
17c. Spectrally selective glass	1	2	3	4	5	6	[17]
17d. Optical shutter of thermally "opacifiable" glass	1	2	3	4	5	6	[18]
17e. Photochromic glass	1	2	3	4	5	6	[19]
17f. Solar control films with adhesive backing	1	2	3	4	5	6	[20]
17g. Tilted window	1	2	3	4	5	6	[21]
18. REFLECTION DEVICES TO BEAM DAYLIGHT INTO WORK ENVIRONMENT							
18a. Light shelves	1	2	3	4	5	6	[22]
18b. Paired reflectors with tilted window	1	2	3	4	5	6	[23]
18c. Adjustable horizontal blinds	1	2	3	4	5	6	[24]
19. CONTROL AIR INFILTRATION/EXFILTRATION							
19a. Increase air tightness	1	2	3	4	5	6	[25]
19b. Reduce total length of joints	1	2	3	4	5	6	[26]
20. IMPROVE INSULATION VALUE OF WINDOWS							
20a. Two parallel identical windows	1	2	3	4	5	6	[27]
20b. Improved frame (thermal breaks, rigid vinyl)	1	2	3	4	5	6	[28]
20c. Improved glazing area (sealed double panes with Krypton gas, heat mirror film)	1	2	3	4	5	6	[29]
20d. Introduce dynamic insulation devices ("Beadwall", night-time closures, blinds, interior insulating roll-up shades)	1	2	3	4	5	6	[30]

INNOVATION	ALREADY AVAILABLE, DEPENDABLE	BY 1985	BY 1990	BY 1995	LATER THAN 1995	NEVER	
	WHEN AVAILABLE AND DEPENDABLE ENOUGH....						
21. NATURAL VENTILATION							
21a. Operable windows	1	2	3	4	5	6	[31]
21b. Ventilation through window frame	1	2	3	4	5	6	[32]
22. COUNTERACT UNCOMFORTABLE MEAN RADIANT TEMPERATURE (near window)							
22a. Increase thermal storage capacity in edge zones (mass floor, panel or ceiling tiles with phase-change core)	1	2	3	4	5	6	[33]
22b. Radiant floor or radiant ceiling	1	2	3	4	5	6	[34]
23. WINDOWS AS COMPREHENSIVE ENVIRONMENT MODIFIERS							
23a. Reversible window with blinds on one side	1	2	3	4	5	6	[35]
23b. Multi-layer mechanized window	1	2	3	4	5	6	[36]
23c. Automatic sensors and controls with manual overrides	1	2	3	4	5	6	[37]
ABOUT ROOFS AND ROOFING							
24. IMPROVED PREFABRICATED INSULATING DECKS	1	2	3	4	5	6	[38]
25. CONTINUOUS ELASTIC ROOFING MEMBRANE							
25a. Single-ply continuous membranes	1	2	3	4	5	6	[39]
26. REDUCTION OF THERMAL SHOCK ON ROOF MEMBRANE							
26a. Through earth covering and planting	1	2	3	4	5	6	[40]

INNOVATION	WHEN AVAILABLE AND DEPENDABLE ENOUGH.... ALREADY AVAILABLE, DEPENDABLE	BY 1985	BY 1990	BY 1995	LATER THAN 1995	NEVER	
27. UTILIZE ROOF AS ENERGY PLANT							
27a. Self-tracking solar concentrators	1	2	3	4	5	6	[41]
27b. Wind generators, etc.	1	2	3	4	5	6	[42]
28. REDUCED SOLAR LOAD ON ROOF							
28a. High parapets; roof-mounted shading devices	1	2	3	4	5	6	[43]
29. OTHER ADDED INNOVATIONS							
29a. ______________________	1	2	3	4	5	6	[44]
29b. ______________________	1	2	3	4	5	6	[45]
29c. ______________________	1	2	3	4	5	6	[46]
29d. ______________________	1	2	3	4	5	6	[47]
29e. ______________________	1	2	3	4	5	6	[48]
29f. ______________________	1	2	3	4	5	6	[49]
29g. ______________________	1	2	3	4	5	6	[50]
29h. ______________________	1	2	3	4	5	6	[51]
29i. ______________________	1	2	3	4	5	6	[52]
29j. ______________________	1	2	3	4	5	6	[53]

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.]

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

INNOVATION	IT IS OF THE GREATEST IMPORTANCE									IT IS OF MINOR IMPORTANCE	
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]

INNOVATION	IT IS OF THE GREATEST IMPORTANCE									IT IS OF MINOR IMPORTANCE	
9. USE OF COMPOSITE MATERIALS											
9a. Surface impregnated cellular concrete	9	8	7	6	5	4	3	2	1	0	[75]
9b. Glass fiber reinforced concrete cladding	9	8	7	6	5	4	3	2	1	0	[76]
9c. Integrated wall panel construction systems	9	8	7	6	5	4	3	2	1	0	[77]
10. USE OF PREFAB MASS WALLS											
10a. Prefab brick wall component	9	8	7	6	5	4	3	2	1	0	[78]
10b. Precast concrete wall component	9	8	7	6	5	4	3	2	1	0	[79]
											0 3 [1-2]
11. USE OF MINIMUM MASS SKIN COMPONENTS											
11a. Sandwich panel systems	9	8	7	6	5	4	3	2	1	0	[3]
11b. Ultra-thin sandwich material	9	8	7	6	5	4	3	2	1	0	[4]
11c. Tinted, heat-absorbing, reflective glass wall	9	8	7	6	5	4	3	2	1	0	[5]
11d. Firestop glazing	9	8	7	6	5	4	3	2	1	0	[6]
12. USE OF BUTT JOINT GLASS PANES (for continuous fenestration)											
12a. Silicone glazing sealants	9	8	7	6	5	4	3	2	1	0	[7]

INNOVATION	IT IS OF THE GREATEST IMPORTANCE									IT IS OF MINOR IMPORTANCE	
13. CONSERVE OPERATIONAL ENERGY BY PASSIVE METHODS FOR METHODS FOR MINIMIZING HEATING/COOLING/LIGHTING LOADS											
13a. Building geometry	9	8	7	6	5	4	3	2	1	0	[8]
13b. Glazed area in wall	9	8	7	6	5	4	3	2	1	0	[9]
13c. Heat loss through joints	9	8	7	6	5	4	3	2	1	0	[10]
13d. Operable windows	9	8	7	6	5	4	3	2	1	0	[11]
13e. Air-to-air heat exchangers	9	8	7	6	5	4	3	2	1	0	[12]
13f. Thermal mass for natural cooling	9	8	7	6	5	4	3	2	1	0	[13]
13g. Trombe walls, solaria, atria, 2nd envelope	9	8	7	6	5	4	3	2	1	0	[14]
14. CONSERVE OPERATIONAL ENERGY BY ACTIVE SYSTEMS											
14a. Absorbers/heat pump	9	8	7	6	5	4	3	2	1	0	[15]
14b. Solar collectors	9	8	7	6	5	4	3	2	1	0	[16]
14c. Photovoltaic cells	9	8	7	6	5	4	3	2	1	0	[17]
14d. Sensors to automatically relate interior environmental control systems to outside conditions for optimal energy management	9	8	7	6	5	4	3	2	1	0	[18]
15. SUN CONTROL WITH EXTERIOR SHADING DEVICES											
15a. Improved overhangs	9	8	7	6	5	4	3	2	1	0	[19]
15b. Use of vines and plants	9	8	7	6	5	4	3	2	1	0	[20]
15c. Use lightweight sun screen	9	8	7	6	5	4	3	2	1	0	[21]
15d. Operable exterior venetian blinds	9	8	7	6	5	4	3	2	1	0	[22]
15e. Adjustable exterior louvers	9	8	7	6	5	4	3	2	1	0	[23]
15f. Fabric shades, awnings	9	8	7	6	5	4	3	2	1	0	[24]
15g. Solar shutters (panels or rolling)	9	8	7	6	5	4	3	2	1	0	[25]

INNOVATION	IT IS OF THE GREATEST IMPORTANCE									IT IS OF MINOR IMPORTANCE	
16. SUN CONTROL WITH INTERIOR SHADING DEVICES											
16a. Improved curtain material	9	8	7	6	5	4	3	2	1	0	[26]
16b. Rollshades (tightly sealing)	9	8	7	6	5	4	3	2	1	0	[27]
16c. Vinyl-coated fabric (semi-transparent or translucent)	9	8	7	6	5	4	3	2	1	0	[28]
16d. Reflective synthetic films	9	8	7	6	5	4	3	2	1	0	[29]
16e. Adjustable louvers, blinds	9	8	7	6	5	4	3	2	1	0	[30]
17. SUN CONTROL IN WINDOW PLANE											
17a. Venetian blinds or shades between glass	9	8	7	6	5	4	3	2	1	0	[31]
17b. Coated, absorbing, tinted glass	9	8	7	6	5	4	3	2	1	0	[32]
17c. Spectrally selective glass	9	8	7	6	5	4	3	2	1	0	[33]
17d. Optical shutter of thermally "opacifiable" glass	9	8	7	6	5	4	3	2	1	0	[34]
17e. Photochromic glass	9	8	7	6	5	4	3	2	1	0	[35]
17f. Solar control films with adhesive backing	9	8	7	6	5	4	3	2	1	0	[36]
17g. Tilted window	9	8	7	6	5	4	3	2	1	0	[37]
18. REFLECTION DEVICES TO BEAM DAYLIGHT INTO WORK ENVIRONMENT											
18a. Light shelves	9	8	7	6	5	4	3	2	1	0	[38]
18b. Paired reflectors with tilted window	9	8	7	6	5	4	3	2	1	0	[39]
18c. Adjustable horizontal blinds	9	8	7	6	5	4	3	2	1	0	[40]
19. CONTROL AIR INFILTRATION/EXFILTRATION											
19a. Increase air tightness	9	8	7	6	5	4	3	2	1	0	[41]
19b. Reduce total length of joints	9	8	7	6	5	4	3	2	1	0	[42]

INNOVATION	IT IS OF THE GREATEST IMPORTANCE									IT IS OF MINOR IMPORTANCE	
20. IMPROVE INSULATION VALUE OF WINDOWS											
20a. Two parallel identical windows	9	8	7	6	5	4	3	2	1	0	[43]
20b. Improved frame (thermal breaks, rigid vinyl)	9	8	7	6	5	4	3	2	1	0	[44]
20c. Improved glazing area (sealed double panes with Krypton gas, heat mirror film)	9	8	7	6	5	4	3	2	1	0	[45]
20d. Introduce dynamic insulation devices ("Beadwall", night-time closures, blinds, interior insulating roll-up shades)	9	8	7	6	5	4	3	2	1	0	[46]
21. NATURAL VENTILATION											
21a. Operable windows	9	8	7	6	5	4	3	2	1	0	[47]
21b. Ventilation through window frame	9	8	7	6	5	4	3	2	1	0	[48]
22. COUNTERACT UNCOMFORTABLE MEAN RADIANT TEMPERATURE (near window)											
22a. Increase thermal storage capacity in edge zones (mass floor, panel or ceiling tiles with phase-change core)	9	8	7	6	5	4	3	2	1	0	[49]
22b. Radiant floor or radiant ceiling	9	8	7	6	5	4	3	2	1	0	[50]
23. WINDOWS AS COMPREHENSIVE ENVIRONMENT MODIFIERS											
23a. Reversible window with blinds on one side	9	8	7	6	5	4	3	2	1	0	[51]
23b. Multi-layer mechanized window	9	8	7	6	5	4	3	2	1	0	[52]
23c. Automatic sensors and controls with manual overrides	9	8	7	6	5	4	3	2	1	0	[53]

INNOVATION	IT IS OF THE GREATEST IMPORTANCE									IT IS OF MINOR IMPORTANCE	
ABOUT ROOFS AND ROOFING											
24. IMPROVED PREFABRICATED INSULATING DECKS	9	8	7	6	5	4	3	2	1	0	[54]
25. CONTINUOUS ELASTIC ROOFING MEMBRANE											
25a. Singly-ply continiuous membranes	9	8	7	6	5	4	3	2	1	0	[55]
26. REDUCTION OF THERMAL SHOCK ON ROOF MEMBRANE											
26a. Through earth covering and planting	9	8	7	6	5	4	3	2	1	0	[56]
27. UTILIZE ROOF AS ENERGY PLANT											
27a. Self-tracking solar concentrators	9	8	7	6	5	4	3	2	1	0	[57]
27b. Wind generators, etc.	9	8	7	6	5	4	3	2	1	0	[58]
28. REDUCED SOLAR LOAD ON ROOF											
28a. High parapets; roof-mounted shading devices	9	8	7	6	5	4	3	2	1	0	[59]
29. OTHER ADDED INNOVATIONS											
29a. ______________________	9	8	7	6	5	4	3	2	1	0	[60]
29b. ______________________	9	8	7	6	5	4	3	2	1	0	[61]
29c. ______________________	9	8	7	6	5	4	3	2	1	0	[62]
29d. ______________________	9	8	7	6	5	4	3	2	1	0	[63]
29e. ______________________	9	8	7	6	5	4	3	2	1	0	[64]
29f. ______________________	9	8	7	6	5	4	3	2	1	0	[65]
29g. ______________________	9	8	7	6	5	4	3	2	1	0	[66]
29h. ______________________	9	8	7	6	5	4	3	2	1	0	[67]
29i. ______________________	9	8	7	6	5	4	3	2	1	0	[68]
29j. ______________________	9	8	7	6	5	4	3	2	1	0	[69]

4. What are the <u>benefits</u>? For up to ten (10) innovations you rated as most important, tell us what you think the <u>major benefits</u> would be of using them in office buildings. Since GSA is a major office builder, describe any benefits you see accruing to a <u>volume builder</u> as well. Please list innovation by the numbers which identify them...for example, 3c refers to "thermographic cameras".

CARDS 4,5,6

INNOVATION MAJOR BENEFITS

INNOVATION	MAJOR BENEFITS

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."

CARDS 7,8,9

INNOVATION	MAJOR CONSTRAINTS

APPENDIX B. Basic Data

Table A1. Estimates of Availability of Structural Innovations

INNOVATION	ALREADY AVAILABLE, DEPENDABLE (PCT)	BY 1985 (PCT)	BY 1990 (PCT)	BY 1995 (PCT)	LATER THAN 1995 (PCT)	NEVER (PCT)
1 -STIFFNESS IN HIGHRISE BUILDINGS						
1a-Frame-truss combination; Outrigger truss; "Tie-down" truss	59.5	16.2	16.2	2.7	5.4	
1b-Exterior steel plate shear walls	40.0	5.7	25.7	5.7	8.6	14.3
1c-Inclined or pyramid-shaped frame	51.3	15.4	7.7	10.3	7.7	7.7
1d-Tubular structures	77.5	12.5	5.0	5.0		
2 -VERTICAL FLEXIBILITY						
2a-Megaframes	19.4	11.1	30.6	11.1	25.0	2.8
2b-Hollow tubular buildings	42.1	7.9	23.7	10.5	13.2	2.6
2c-Exterior shafts	32.4	20.6	17.6	20.6	8.8	
2d-Vertically curved or folded plate walls as support	14.3	11.4	25.7	14.3	20.0	14.3
3 -WIND RESISTANT DESIGN						
3a-Aerodynamically stable building forms	31.7	12.2	17.1	14.6	19.5	4.9
3b-Drag reduction	12.8	17.9	7.7	30.8	15.4	15.4
4 -SEISMIC DESIGN						
4a-Y-shape box columns	18.8	15.6	37.5	12.5	15.6	
4b-Eliminate "soft storey"	42.9	20.0	20.0	8.6	5.7	2.9
4c-Shear walls graduated by height	61.5	17.9	17.9	2.6		

Table A1. Estimates of Availability of Structural Innovations (Cont.)

INNOVATION	ALREADY AVAILABLE, DEPENDABLE (PCT)	BY 1985 (PCT)	BY 1990 (PCT)	BY 1995 (PCT)	LATER THAN 1995 (PCT)	NEVER (PCT)
4d-For very large bldgs, ensure appropriate dimensions or seismic subdiv	47.4	21.1	13.2	7.9	7.9	2.6
4e-Ensure vertical continuity or seismic separation at setbacks	47.2	11.1	11.1	16.7	8.3	5.6
4f-Eccentric braced frames	50.0	15.8	23.7	5.3	5.3	
4g-Flexible sliding foundation	2.5	10.0	22.5	20.0	25.0	20.0
5 -STRUCTURAL DAMPING						
5a-Active damping control	28.2	12.8	28.2	10.3	17.9	2.6
5b-Visco-elastic damping	18.9	16.2	32.4	16.2	10.8	5.4
5c-Damping friction at bolted connections	15.4	17.9	28.2	10.3	17.9	10.3
6 -MATERIAL DEVELOPMENT						
6a-Light-weight, high-strength, reinforced concrete	45.0	10.0	30.0	2.5	10.0	2.5
7 -FOUNDATIONS						
7a-Mixed-in-place stabilizers	42.9	17.1	20.0	14.3	2.9	2.9
7b-Preconsolidation	78.4	5.4	8.1	8.1		
7c-Reinforced earth	50.0	13.9	11.1	19.4	2.8	2.8
8 -COMPOSITE STRUCTURE						
8a-Concrete exterior, steel interior frame	77.5	5.0	10.0	2.5	5.0	
8b-Steel plate cladding bonded to concrete members	15.8	26.3	10.5	18.4	15.8	13.2

Table A1. Estimates of Availability of Structural Innovations (Cont.)

INNOVATION	ALREADY AVAILABLE, DEPENDABLE (PCT)	BY 1985 (PCT)	BY 1990 (PCT)	BY 1995 (PCT)	LATER THAN 1995 (PCT)	NEVER (PCT)
8c-Steel and reinforced concrete construction	89.7	5.1	2.6	2.6		
9 -EXTERIOR FINISH						
9a-Controlled rust steel or stainless steel	53.8	12.3	5.1	12.8	7.7	7.7
10 -FIRE PROTECTION						
10a-Water cooled structural members	35.0	10.0	22.5	10.0	12.5	10.0
10b-Fire resisting paint	23.7	15.8	26.3	15.8	13.2	5.3
11 -RELOCATABLE BUILDINGS						
11a-Unit construction or modular space frame	48.7	5.1	15.4	23.1	7.7	
11b-Plastic "umbrella"	17.1	8.6	28.6	22.9	22.9	
11c-Suspension cable structure	66.7	2.6	15.4	7.7	5.1	2.6
11d-Fabric structure	60.5	7.9	15.8	10.5	2.6	2.6
12 -MASS REDUCTION AND INCREASED DUCTILITY						
12a-Lightweight alloys	18.4	7.9	23.7	21.1	26.3	2.6
12b-Plastics	5.4	13.5	18.9	10.8	45.9	5.4
12c-Tension structures	52.5	5.0	15.0	15.0	10.0	2.5
13 -FLEXIBLE SERVICES						
13a-Interstitial space	69.2	5.1	17.9	7.7		
13b-Exterior shafts, ducts	59.5	5.4	21.6	8.1	5.4	

Table A1. Estimates of Availability of Structural Innovations (Cont.)

INNOVATION	ALREADY AVAILABLE, DEPENDABLE (PCT)	BY 1985 (PCT)	BY 1990 (PCT)	BY 1995 (PCT)	LATER THAN 1995 (PCT)	NEVER (PCT)
14 -PREFABRICATION/INDUSTRIALIZATION						
14a-Large scale prefabricated-pre-finished structural elements	51.3	2.6	23.1	12.8	10.3	
14b-Large scale facade elements	64.9	10.8	13.5	5.4	5.4	
14c-Industrialized systems	64.1	7.7	7.7	10.3	10.3	
14d-Prefab space modules	48.7	12.8	12.8	10.3	12.8	2.6
14e-Post tensioning	87.8	4.9	4.9			2.4
14f-Composite steel/precast concrete structural systems	72.5	10.0	15.0		2.5	
14g-Robotics	2.6	13.2	34.2	18.4	28.9	2.6
14h-Computer-aided construction	23.1	17.9	30.8	15.4	10.3	2.6
14i-Fabric structures	43.9	12.2	19.5	14.6	7.3	2.4

Table A2. Estimates of Importance of Structural Innovations

INNOVATION	GREATEST IMPORTANCE 9 (PCT)	8	7	6	5	4	3	2	MINOR IMPORTANCE 1	0 (PCT)
1 -STIFFNESS IN HIGHRISE BUILDINGS										
1a-Frame-truss combination; Outrigger truss; "Tie-down" truss	12.2	7.3	24.4	12.2	22.0	4.9	2.4	4.9	2.4	7.3
1b-Exterior steel plate shear walls	9.8	4.9	12.2	9.8	12.2	9.8	14.6	12.2	4.9	9.8
1c-Inclined or pyramid-shaped frame	4.9	4.9	9.8	14.6	22.0	9.8	9.8	14.6	2.4	7.3
1d-Tubular structures	46.3	7.3	17.1	14.6	4.9	4.9				4.9
2 -VERTICAL FLEXIBILITY										
2a-Megaframes	4.9	9.8	19.5	12.2	22.0		9.8	7.3	7.3	7.3
2b-Hollow tubular buildings	22.0	14.6	7.3	14.6	14.6		9.8	4.9	4.9	7.3
2c-Exterior shafts	9.8	7.3	19.5	7.3	24.4		9.8	4.9	4.9	12.2
2d-Vertically curved or folded plate walls as support	2.4	4.9	14.6	9.8	17.1	7.3	12.2	9.8	4.9	17.1
3 -WIND RESISTANT DESIGN										
3a-Aerodynamically stable building forms	31.7	17.1	14.6	14.6	12.2		2.4	2.4	2.4	2.4
3b-Drag reduction	19.5	4.9	22.0	17.1	9.8	2.4	14.6		4.9	4.9
4 -SEISMIC DESIGN										
4a-Y-shape box columns	2.4	7.3	12.2	9.8	34.1	7.3	4.9	2.4	7.3	12.2
4b-Eliminate "soft storey"	17.1	19.5	17.1	4.9	24.4	2.4	2.4			12.2
4c-Shear walls graduated by height	9.8	24.4	17.1	17.1	12.2	4.9	2.4			12.2

Table A2. Estimates of Importance of Structural Innovations (Cont.)

INNOVATION	GREATEST IMPORTANCE 9 (PCT)	8	7	6	5	4	3	2	1	MINOR IMPORTANCE 0 (PCT)
4d-For very large bldgs, ensure appropriate dimensions or seismic subdiv	36.6	12.2	19.5	14.6	4.9		7.3			4.9
4e-Ensure vertical continuity or seismic separation at setbacks	29.3	14.6	26.8	7.3	9.8	2.4	4.9			4.9
4f-Eccentric braced frames	14.6	17.1	12.2	14.6	22.0	7.3	2.4	2.4		7.3
4g-Flexible sliding foundation	7.3	7.3	9.8	12.2	19.5	9.8	12.2	2.4	9.8	9.8
5 -STRUCTURAL DAMPING										
5a-Active damping control	17.1	19.5	7.3	7.3	9.8	19.5	7.3	2.4	4.9	4.9
5b-Visco-elastic damping	17.1	9.8	9.8	22.0	14.6	2.4	9.8	2.4	2.4	9.8
5c-Damping friction at bolted connections	12.2	9.8	22.0	7.3	22.0	9.8		2.4	7.3	7.3
6 -MATERIAL DEVELOPMENT										
6a-Light-weight, high-strength, reinforced concrete	43.9	29.3	7.3	7.3	4.9	4.9		2.4		
7 -FOUNDATIONS										
7a-Mixed-in-place stabilizers	9.8	14.6	24.4	14.6	7.3	12.2	7.3	2.4	2.4	4.9
7b-Preconsolidation	14.6	24.4	19.5	12.2	9.8	9.8	2.4	2.4		4.9
7c-Reinforced earth	12.2	12.2	17.1	12.2	22.0	9.8	4.9	4.9		4.9
8 -COMPOSITE STRUCTURE										
8a-Concrete exterior, steel interior frame	19.5	19.5	26.8	9.8	9.8	9.8	2.4	2.4		
8b-Steel plate cladding bonded to concrete members		4.9	17.1	17.1	26.8	9.8	12.2	4.9	4.9	2.4

Table A2. Estimates of Importance of Structural Innovations (Cont.)

INNOVATION	GREATEST IMPORTANCE 9 (PCT)	8	7	6	5	4	3	2	1	MINOR IMPORTANCE 0 (PCT)
8c-Steel and reinforced concrete construction	43.9	26.8	4.9	17.1		2.4	4.9			
9 -EXTERIOR FINISH										
9a-Controlled rust steel or stainless steel	12.2	7.3	19.5	19.5	9.8	14.6	4.9	7.3		4.9
10 -FIRE PROTECTION										
10a-Water cooled structural members	4.9	4.9	12.2	9.8	14.6	17.1	17.1	7.3	12.2	
10b-Fire resisting paint	4.9	2.4	4.9	7.3	7.3	9.8	9.8	17.1	9.8	26.8
11 -RELOCATABLE BUILDINGS										
11a-Unit construction or modular space frame	14.6	17.1	22.0	14.6	12.2	7.3	2.4	2.4	4.9	2.4
11b-Plastic "umbrella"	2.4	2.4	9.8	9.8	22.0	4.9	24.4	12.2	2.4	9.8
11c-Suspension cable structure	9.8	19.5	12.2	14.6	12.2	9.8	7.3	7.3	4.9	2.4
11d-Fabric structure	9.8	14.6	19.5	14.6	17.1	7.3	7.3	2.4	4.9	2.4
12 -MASS REDUCTION AND INCREASED DUCTILITY										
12a-Lightweight alloys	26.8	9.8	9.8	17.1	17.1	4.9	2.4	2.4	4.9	4.9
12b-Plastics	22.0	2.4	14.6	12.2	14.6	7.3	9.8	7.3	4.9	4.9
12c-Tension structures	19.5	7.3	22.0	14.6	22.0	4.9	4.9	2.4	2.4	
13 -FLEXIBLE SERVICES										
13a-Interstitial space	26.8	12.2	24.4	14.6	12.2	4.9	2.4			2.4
13b-Exterior shafts, ducts	14.6	12.2	24.4	9.8	19.5	9.8	4.9		2.4	2.4

Table A2. Estimates of Importance of Structural Innovations (Cont.)

INNOVATION	GREATEST IMPORTANCE 9 (PCT)	8	7	6	5	4	3	2	1	MINOR IMPORTANCE 0 (PCT)
14 -PREFABRICATION/INDUSTRIALIZATION										
14a-Large scale prefabricated-pre-finished structural elements	24.4	24.4	17.1	12.2	4.9	4.9	9.8			2.4
14b-Large scale facade elements	22.0	24.4	17.1	17.1	9.8	2.4	4.9			2.4
14c-Industrialized systems	17.1	29.3	22.0	12.2	9.8	2.4	4.9			2.4
14d-Prefab space modules	7.3	17.1	24.4	22.0	9.8	7.3	7.3	2.4		2.4
14e-Post tensioning	24.4	29.3	14.6	14.6	7.3	4.9		2.4		2.4
14f-Composite steel/precast concrete structural systems	34.1	12.2	19.5	12.2	12.2	4.9	2.4			2.4
14g-Robotics	14.6	17.1	14.6	19.5	12.2	2.4	2.4	4.9		12.2
14h-Computer-aided construction	29.3	29.3	17.1	7.3	7.3					9.8
14i-Fabric structures	14.6	14.6	12.2	17.1	22.0	4.9	12.2		2.4	

Table A3. Estimates of Availability of Enclosure Innovations

INNOVATION	ALREADY AVAILABLE, DEPENDABLE (PCT)	BY 1985 (PCT)	BY 1990 (PCT)	BY 1995 (PCT)	LATER THAN 1995 (PCT)	NEVER (PCT)
1 -INTER-BUILDING CIRCULATION AND CLIMATIC BUFFER ZONES						
1a-Pedestrian bridges (skyways) and clip-on corridors	78.6	3.6	7.1	3.6	3.6	3.6
1b-Enclosing space between buildings	60.7	7.1	25.0	3.6		3.6
1c-Solaria (designed in or clip-on)	38.5	11.5	38.5	3.8	7.7	
1d-Super-envelope over a group of buildings	3.6		17.9	10.7	53.6	14.3
2 -NEW MATERIALS WHICH ALTER ENCLOSURE FORMS						
2a-Modern "permanent" fabric structures (cable restrain,air support,etc.)	48.3	3.4	27.6		10.3	10.3
3 -SOPHISTICATED DESIGN/EVALUATION PROCEDURES						
3a-Computer generated facades	3.7	40.7	37.0	7.4	3.7	7.4
3b-Design using solar envelopes	11.1	25.9	29.6	18.5	14.8	
3c-Thermographic cameras to detect leaks	40.7	18.5	18.5	3.7	14.8	3.7
3d-Thermal modelling in design	7.7	34.6	38.5	15.4		3.8
4 -REDUCE HIGH-WIND EFFECTS						
4a-Wind resistant design	57.1	3.6	14.3	10.7	10.7	3.6
4b-"Roughen" perimeter surface with protrusions, setbacks, etc.	23.1	19.2	19.2	19.2	11.5	7.7
5 -MINIMIZE RAINWATER PENETRATION THROUGH JOINTS						
5a-Reduce joints	55.6	7.4	14.8	7.4	7.4	7.4
5b-Water tighten joints	53.6	7.1	25.0	3.6	3.6	7.1

Table A3. Estimates of Availability of Enclosure Innovations (Cont.)

INNOVATION	ALREADY AVAILABLE, DEPENDABLE (PCT)	BY 1985 (PCT)	BY 1990 (PCT)	BY 1995 (PCT)	LATER THAN 1995 (PCT)	NEVER (PCT)
5c-Use rainscreen/decompression chamber/drained joint	20.0	20.0	24.0	28.0	4.0	4.0
6 -FACILITATE FUTURE FACADE CHANGES						
6a-Interchangeable components and access to building's exterior	3.6	3.6	35.7	14.3	25.0	17.9
7 -USE OF HOMOGENOUS, INORGANIC CELLULAR MATERIALS						
7a-Cellular or foamed glass	17.9	10.7	42.9	17.9	10.7	
7b-Cellular or aerated concrete	14.8	7.4	55.6	18.5	3.7	
7c-Foamed ceramic bricks			57.7	23.1	15.4	3.8
8 -USE OF THERMAL INSULATION MATERIALS FOR EXTREME OUTSIDE OF EXTERIOR WALL						
8a-External insulation	29.6	22.2	25.9	14.8	3.7	3.7
8b-Surface coated porous fire clay		8.3	41.7	25.0	16.7	8.3
8c-Insulating ceramic tiles		8.3	50.0	12.5	25.0	4.2
9 -USE OF COMPOSITE MATERIALS						
9a-Surface impregnated cellular concrete	4.0	24.0	48.0	20.0	4.0	
9b-Glass fiber reinforced concrete cladding	22.2	29.6	29.6	14.8		3.7
9c-Integrated wall panel construction systems	70.4	11.1	14.8			3.7
10 -USE OF PREFAB MASS WALLS						
10a-Prefab brick wall component	71.4	10.7	17.9			

Table A3. Estimates of Availability of Enclosure Innovations (Cont.)

INNOVATION	ALREADY AVAILABLE, DEPENDABLE (PCT)	BY 1985 (PCT)	BY 1990 (PCT)	BY 1995 (PCT)	LATER THAN 1995 (PCT)	NEVER (PCT)
10b-Precast concrete wall component	93.1	6.9				
11 -USE OF MINIMUM MASS SKIN COMPONENTS						
11a-Sandwich panel systems	85.7	3.6	7.1	3.6		
11b-Ultra-thin sandwich material	11.5	19.2	38.5	19.2	11.5	
11c-Tinted, heat-absorbing, reflective glass wall	59.3	18.5	18.5	3.7		
11d-Firestop glazing	14.3	14.3	33.3	23.8	9.5	4.8
12 -USE OF BUTT JOINT GLASS PANES (for continuous fenestration)						
12a-Silicone glazing sealants	57.7	7.7	26.9		3.8	3.8
13 -PASSIVE METHODS FOR METHODS FOR MINIMIZING HEAT'G/COOL'G/LIGHT'G						
13a-Building geometry	69.0	10.3	17.2	3.4		
13b-Glazed area in wall	64.3	3.6	25.0	7.1		
13c-Heat loss through joints	51.9	14.8	29.6	3.7		
13d-Operable windows	71.4	7.1	14.3	7.1		
13e-Air-to-air heat exchangers	44.4	22.2	25.9	7.4		
13f-Thermal mass for natural cooling	40.7	14.8	29.6	7.4	7.4	
13g-Trombe walls, solaria, atria, 2nd envelope	24.0	20.0	36.0	16.0	4.0	
14 -CONSERVE OPERATIONAL ENERGY BY ACTIVE SYSTEMS						

Table A3. Estimates of Availability of Enclosure Innovations (Cont.)

INNOVATION	ALREADY AVAILABLE, DEPENDABLE (PCT)	BY 1985 (PCT)	BY 1990 (PCT)	BY 1995 (PCT)	LATER THAN 1995 (PCT)	NEVER (PCT)
14a-Absorbers/heat pump	65.4	15.4	7.7	7.7	3.8	
14b-Solar collectors	50.0	7.1	32.1	7.1	3.6	
14c-Photovoltaic cells	15.4	3.8	30.8	23.1	23.1	3.8
14d-Sensors to automatically relate interior envir. to outside cond.	23.1	30.8	23.1	15.4	7.7	
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						
16a-Improved curtain material	42.3	30.8	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	

Table A3. Estimates of Availability of Enlosure Innovations (Cont.)

INNOVATION	ALREADY AVAILABLE, DEPENDABLE (PCT)	BY 1985 (PCT)	BY 1990 (PCT)	BY 1995 (PCT)	LATER THAN 1995 (PCT)	NEVER (PCT)
16e-Adjustable louvers, blinds	78.6	14.3	3.6		3.6	
17 -SUN CONTROL IN WINDOW PLANE						
17a-Venetian blinds or shades between glass	55.6	11.1	22.2	3.7	3.7	3.7
17b-Coated, absorbing, tinted glass	77.8	7.4	14.8			
17c-Spectrally selective glass	12.5	16.7	54.2	12.5	4.2	
17d-Optical shutter of thermally "opacifiable" glass		5.0	55.0	35.0	5.0	
17e-Photochromic glass	4.5	4.5	22.7	45.5	22.7	
17f-Solar control films with adhesive backing	48.0	16.0	16.0	20.0		
17g-Tilted window	64.0	16.0	4.0	8.0	4.0	4.0
18 -REFLECTION DEVICES TO BEAM DAYLIGHT INTO WORK ENVIRONMENT						
18a-Light shelves	37.5	20.8	29.9	4.2	4.2	4.2
18b-Paired reflectors with tilted window	21.7	21.7	39.1		8.7	8.7
18c-Adjustable horizontal blinds	52.2	21.7	21.7		4.3	
19 -CONTROL AIR INFILTRATION/EXFILTRATION						
19a-Increase air tightness	61.5	19.2	11.5	7.7		
19b-Reduce total length of joints	46.2	15.4	23.1	7.7	3.8	3.8

Table A3. Estimates of Availability of Enclosure Innovations (Cont.)

INNOVATION	ALREADY AVAILABLE, DEPENDABLE (PCT)	BY 1985 (PCT)	BY 1990 (PCT)	BY 1995 (PCT)	LATER THAN 1995 (PCT)	NEVER (PCT)
20 -IMPROVE INSULATION VALUE OF WINDOWS						
20a-Two parallel identical windows	64.0	8.0	12.0	4.0		12.0
20b-Improve frame (thermal breaks, rigid vinyl)	57.7	23.1	15.4	3.8		
20c-Improve glazing area (double panes w/ Krypton gas, heated mirror film)	25.0	25.0	33.3	4.2	8.3	4.2
20d-Introduce dynamic insulation devices ("Beadwall", blinds, roll-up shades)	16.0	20.0	40.0	16.0	4.0	4.0
21 -NATURAL VENTILATION						
21a-Operable windows	89.3	3.6	3.6	3.6		
21b-Ventilation through window frame	32.0	28.0	36.0	4.0		
22 -COUNTERACT UNCOMFORTABLE MEAN RADIANT TEMPERATURE (near window)						
22a-Increase thermal storage capacity in edge zones (phase-change panels)	8.3	25.0	62.5	4.2		
22b-Radiant floor or radiant ceiling	50.0	12.5	33.3	4.2		
23 -WINDOWS AS COMPREHENSIVE ENVIRONMENT MODIFIERS						
23a-Reversible window with blinds on one side	12.0	20.0	36.0	12.0	12.0	8.0
23b-Multi-layer mechanized window	8.0	16.0	40.0	12.0	24.0	
23c-Automatic sensors and controls with manual overrides	12.0	12.0	48.0	16.0	12.0	
24 -IMPROVED PREFABRICATED INSULATING DECKS	36.0	16.0	40.0	4.0	4.0	
25 -CONTINUOUS ELASTIC ROOFING MEMBRANE						
25a-Single-ply continuous membranes	62.1	13.8	17.2	3.4		3.4

Table A3. Estimates of Availability of Enclosure Innovations (Cont.)

INNOVATION	ALREADY AVAILABLE, DEPENDABLE (PCT)	BY 1985 (PCT)	BY 1990 (PCT)	BY 1995 (PCT)	LATER THAN 1995 (PCT)	NEVER (PCT)
26 -REDUCTION OF THERMAL SHOCK ON ROOF MEMBRANE						
26a-Through earth covering and planting	44.8	13.8	17.2	10.3	3.4	10.3
27 -UTILIZE ROOF AS ENERGY PLANT						
27a-Self-tracking solar concentrators	3.7	18.5	48.1	7.4	18.5	3.7
27b-Wind generators, etc.	7.7	15.4	26.9	15.4	30.8	3.8
28 -REDUCED SOLAR LOAD ON ROOF						
28a-High parapets; roof-mounted shading devices	32.0	20.0	28.0		8.0	12.0

Table A4. Estimates of Importance of Enclosure Innovations

INNOVATION	GREATEST IMPORTANCE 9 (PCT)	8	7	6	5	4	3	2	1	MINOR IMPORTANCE 0 (PCT)
1 -INTER-BUILDING CIRCULATION AND CLIMATIC BUFFER ZONES										
1a-Pedestrian bridges (skyways) and clip-on corridors	13.8	6.9	17.2	13.8	6.9	10.3	6.9	3.4	17.2	3.4
1b-Enclosing space between buildings	13.8	10.3	10.3	20.7	13.8	17.2		3.4		10.3
1c-Solaria (designed in or clip-on)	10.3	3.4	17.2	10.3	13.8	17.2	6.9	3.4	6.9	10.3
1d-Super-envelope over a group of buildings	10.3	10.3	17.2	3.4	10.3	17.2	10.3	13.8		6.9
2 -NEW MATERIALS WHICH ALTER ENCLOSURE FORMS										
2a-Modern "permanent" fabric structures (cable restrain,air support,etc.)	10.3	6.9	27.6	17.2	13.8	6.9	10.3	3.4		3.4
3 -SOPHISTICATED DESIGN/EVALUATION PROCEDURES										
3a-Computer generated facades	17.2	3.4	24.1	6.9	17.2	10.3	3.4	3.4		13.8
3b-Design using solar envelopes	6.9	17.2	34.5	20.7	13.8	3.4				3.4
3c-Thermographic cameras to detect leaks	13.8	10.3	17.2	20.7	6.9	6.9	6.9	13.8		3.4
3d-Thermal modelling in design	24.1	24.1	10.3	24.1	3.4	3.4		3.4		6.9
4 -REDUCE HIGH-WIND EFFECTS										
4a-Wind resistant design	31.0	13.8	6.9	3.4	20.7	6.9	13.8			3.4
4b-"Roughen" perimeter surface with protrusions, setbacks, etc.	10.3	3.4	13.8	10.3	13.8	20.7	6.9	6.9	10.3	3.4
5 -MINIMIZE RAINWATER PENETRATION THROUGH JOINTS										
5a-Reduce joints	34.5	6.9	17.2	10.3	13.8	3.4	6.9	3.4	3.4	
5b-Water tighten joints	51.7	20.7	6.9	3.4	6.9	3.4	6.9			

Table A4. Estimates of Importance of Enclosure Innovations (Cont.)

INNOVATION	GREATEST IMPORTANCE 9 (PCT)	8	7	6	5	4	3	2	1	MINOR IMPORTANCE 0 (PCT)
5c-Use rainscreen/decompression chamber/drained joint	6.9	10.3	17.2	17.2	24.1	3.4	6.9	3.4		10.3
6 -FACILITATE FUTURE FACADE CHANGES										
6a-Interchangeable components and access to building's exterior		3.4	27.6	10.3	27.6	6.9		10.3	10.3	3.4
7 -USE OF HOMOGENOUS, INORGANIC CELLULAR MATERIALS										
7a-Cellular or foamed glass	6.9	10.3	20.7	17.2	17.2	13.8	3.4	3.4		6.9
7b-Cellular or aerated concrete	6.9		27.6	17.2	10.3	17.2	6.9	3.4		10.3
7c-Foamed ceramic bricks			20.7	13.8	27.6	17.2	3.4	6.9		10.3
8 -USE OF THERMAL INSULATION MATERIALS FOR EXTREME OUTSIDE OF EXTERIOR WALL										
8a-External insulation	31.0	10.3	10.3	3.4	13.8	17.2	6.9		3.4	3.4
8b-Surface coated porous fire clay			20.7	13.8	31.0	6.9	13.8	6.9	3.4	3.4
8c-Insulating ceramic tiles			20.7	13.8	31.8	13.8	13.8		3.4	3.4
9 -USE OF COMPOSITE MATERIALS										
9a-Surface impregnated cellular concrete	3.4	6.9	27.6	20.7	20.7	3.4	3.4	3.4		10.3
9b-Glass fiber reinforced concrete cladding	17.2	10.3	17.2	24.1	10.3	6.9	6.9			6.9
9c-Integrated wall panel construction systems	34.5	10.3	20.7	13.8	3.4	3.4	6.9			6.9
10 -USE OF PREFAB MASS WALLS										
10a-Prefab brick wall component	27.6	3.4	24.1	10.3	10.3	10.3	10.3			3.4

Table A4. Estimates of Importance of Enlosure Innovations (Cont.)

INNOVATION	GREATEST IMPORTANCE 9 (PCT)	8	7	6	5	4	3	2	1	MINOR IMPORTANCE 0 (PCT)
10b-Precast concrete wall component	41.4	10.3	13.8	10.3	6.9	6.9	6.9			3.4
11 -USE OF MINIMUM MASS SKIN COMPONENTS										
11a-Sandwich panel systems	41.4	13.8	13.8	20.7		3.4		6.9		
11b-Ultra-thin sandwich material	10.3	13.8	17.2	10.3	13.8	10.3	6.9	6.9	3.4	6.9
11c-Tinted, heat-absorbing, reflective glass wall	17.2		34.5	20.7	6.9	13.8		3.4		3.4
11d-Firestop glazing	10.3	3.4	10.3	24.1	20.7	10.3		10.3		10.3
12 -USE OF BUTT JOINT GLASS PANES (for continuous fenestration)										
12a-Silicone glazing sealants	20.7	10.3	13.8	24.1	13.8	6.9	3.4	3.4	3.4	
13 -PASSIVE METHODS FOR METHODS FOR MINIMIZING HEAT'G/COOL'G/LIGHT'G										
13a-Building geometry	48.3	17.2	17.2	6.9	3.4	6.9				
13b-Glazed area in wall	31.0	6.9	34.5	10.3	10.3		3.4			3.4
13c-Heat loss through joints	27.6	10.3	20.7	24.1	6.9	3.4		3.4		3.4
13d-Operable windows	17.2	20.7	13.8	20.7	13.8	3.4	6.9			3.4
13e-Air-to-air heat exchangers	10.3	13.8	17.2	13.8	24.1	6.9	3.4			10.3
13f-Thermal mass for natural cooling	13.8	10.3	27.6	6.9	13.8	10.3	3.4	3.4		10.3
13g-Trombe walls, solaria, atria, 2nd envelope	6.9	17.2	17.2	13.8	24.1	6.9	6.9			6.9
14 -CONSERVE OPERATIONAL ENERGY BY										

Table A4. Estimates of Importance of Enclosure Innovations (Cont.)

INNOVATION	GREATEST IMPORTANCE 9 (PCT)	8	7	6	5	4	3	2	1	MINOR IMPORTANCE 0 (PCT)
ACTIVE SYSTEMS										
14a-Absorbers/heat pump	37.9	6.9	13.8	20.7	10.3	3.4	3.4			3.4
14b-Solar collectors	31.0	17.2	20.7	13.8	6.9	6.9	3.4			
14c-Photovoltaic cells	27.6	17.2	20.7	13.8	10.3			3.4		6.9
14d-Sensors to automatically relate interior envir. to outside cond.	34.5	31.0	6.9	6.9	10.3		3.4			6.9
15 -SUN CONTROL WITH EXTERIOR SHADING DEVICES										
15a-Improve overhangs	34.5	17.2	17.2	13.8		3.4	10.3			3.4
15b-Use of vines and plants	10.3	17.2	20.7	3.4	13.8	6.9	17.2	3.4	6.9	
15c-Use lightweight sun screen	20.7	10.3	17.2	20.7	10.3	6.9	6.9	6.9		
15d-Operable exterior venetian blinds	10.3	13.8	17.2	3.4	13.8	13.8	10.3	3.4		13.8
15e-Adjustable exterior louvers	13.8	13.8	27.6	10.3	13.8		17.2			3.4
15f-Fabric shades, awnings	10.3	6.9	24.1	3.4	13.8	13.8	20.7		3.4	3.4
15g-Solar shutters (panels or rolling)	13.8	3.4	41.4	6.9	6.9	10.3	6.9			10.3
16 -SUN CONTROL WITH INTERIOR SHADING DEVICE										
16a-Improved curtain material	24.1	6.9	20.7	10.3	13.8	13.8	3.4			6.9
16b-Rollshades (tightly sealing)	10.3	6.9	24.1	13.8	17.2	10.3	6.9			10.3
16c-Vinyl-coated fabric (semi-transparent or translucent)	10.3	6.9	17.2	17.2	27.6	6.9	10.3			3.4

Table A4. Estimates of Importance of Enclosure Innovations (Cont.)

INNOVATION	GREATEST IMPORTANCE 9 (PCT)	8	7	6	5	4	3	2	1	MINOR IMPORTANCE 0 (PCT)
16d-Reflective synthetic films	17.2	3.4	17.2	10.3	24.1		17.2	6.9		3.4
16e-Adjustable louvers, blinds	20.7	10.3	17.2	17.2	17.2		13.8			3.4
17 -SUN CONTROL IN WINDOW PLANE										
17a-Venetian blinds or shades between glass	10.3	3.4	27.6	6.9	31.0	6.9	6.9			6.9
17b-Coated, absorbing, tinted glass	31.0	6.9	17.2	13.8	13.8	3.4	3.4	3.4		6.9
17c-Spectrally selective glass	10.3	10.3	13.8	20.7	10.3	10.3	3.4	6.9		13.8
17d-Optical shutter of thermally "opacifiable" glass	10.3	6.9	13.8	17.2	17.2	6.9	3.4		3.4	20.7
17e-Photochromic glass	6.9	10.3	10.3	10.3	31.0	6.9	3.4		3.4	17.2
17f-Solar control films with adhesive backing	10.3	10.3	10.3	13.8	20.7	3.4	13.8	6.9	3.4	6.9
17g-Tilted window	13.8	6.9	6.9	13.8	20.7	10.3	6.9	6.9	3.4	10.3
18 -REFLECTION DEVICES TO BEAM DAYLIGHT INTO WORK ENVIRONMENT										
18a-Light shelves	17.2	6.9	20.7	10.3	13.8	3.4	10.3	3.4		13.8
18b-Paired reflectors with tilted window	10.3	6.9	27.6	6.9	13.8		20.7		3.4	10.3
18c-Adjustable horizontal blinds	6.9	10.3	24.1	13.8	13.8	6.9	10.3	3.4		10.3
19 -CONTROL AIR INFILTRATION/EXFILTRATION										
19a-Increase air tightness	37.9	20.7	6.9	17.2	10.3		6.9			
19b-Reduce total length of joints	31.0	17.2	13.8	17.2	10.3		6.9	3.4		

Table A4. Estimates of Importance of Enclosure Innovations (Cont.)

INNOVATION	GREATEST IMPORTANCE 9 (PCT)	8	7	6	5	4	3	2	1	MINOR IMPORTANCE 0 (PCT)
20 -IMPROVE INSULATION VALUE OF WINDOWS										
20a-Two parallel identical windows	10.3	17.2	13.8	10.3	10.3	6.9	6.9	10.3		13.8
20b-Improve frame (thermal breaks, rigid vinyl)	10.3	27.6	17.2	20.7	13.8		3.4			6.9
20c-Improve glazing area (double panes w/ Krypton gas, heated mirror film)	20.7	20.7	20.7	17.2	3.4	3.4			3.4	10.3
20d-Introduce dynamic insulation devices ("Beadwall", blinds, roll-up shades)	10.3	3.4	34.5	24.1	13.8		3.4			10.3
21 -NATURAL VENTILATION										
21a-Operable windows	31.0	17.2	10.3	10.3	10.3	6.9	3.4	10.3		
21b-Ventilation through window frame	10.3	13.8	10.3	13.8	17.2	13.8		13.8		6.9
22 -COUNTERACT UNCOMFORTABLE MEAN RADIANT TEMPERATURE (near window)										
22a-Increase thermal storage capacity in edge zones (phase-change panels)	13.8	3.4	27.6	17.2	24.1			3.4	3.4	6.9
22b-Radiant floor or radiant ceiling	10.3	13.8	17.2	13.8	20.7	6.9	3.4	3.4	3.4	6.9
23 -WINDOWS AS COMPREHENSIVE ENVIRONMENT MODIFIERS										
23a-Reversible window with blinds on one side		3.4	13.8	6.9	24.1	6.9	27.6	3.4	3.4	10.3
23b-Multi-layer mechanized window		10.3	6.9	20.7	20.7	10.3	17.2	3.4		10.3
23c-Automatic sensors and controls with manual overrides	17.2	3.4	20.7	17.2	10.3	10.3	6.9	3.4		10.3
24 -IMPROVED PREFABRICATED INSULATING DECKS	34.5	20.7	17.2	3.4	10.3	6.9				6.9
25 -CONTINUOUS ELASTIC ROOFING MEMBRANE										

Table A4. Estimates of Importance of Enclosure Innovations (Cont.)

INNOVATION	GREATEST IMPORTANCE 9 (PCT)	8	7	6	5	4	3	2	1	MINOR IMPORTANCE 0 (PCT)
25a-Single-ply continuous membranes	41.4	24.1	13.8	10.3		3.4	3.4	3.4		
26 -REDUCTION OF THERMAL SHOCK ON ROOF MEMBRANE										
26a-Through earth covering and planting	17.2	6.9	20.7	3.4	6.9	17.2	10.3	13.8		3.4
27 -UTILIZE ROOF AS ENERGY PLANT										
27a-Self-tracking solar concentrators	13.8	6.9	37.9	10.3	13.8	6.9	3.4			6.9
27b-Wind generators, etc.	6.9	6.9	17.2	13.8	24.1	10.3	3.4	3.4		13.8
28 -REDUCED SOLAR LOAD ON ROOF										
28a-High parapets; roof-mounted shading devices	17.2	13.8	13.8	13.8	6.9	6.9	6.9	6.9	3.4	10.3

Table A5. Benefits of Selected Structural Innovations

INNOVATION	BENEFITS: COST (PCT)	TIME	STRUCTURAL INTEGRITY	DESIGN	AESTHETICS	CONSTRUCTION	QUALITY	REDUCED WEIGHT/HEIGHT	EFFICIENCY	ACCEPTANCE	ENERGY CONSERVATION	OTHER (PCT)
1 -STIFFNESS IN HIGHRISE BUILDINGS												
1a-Frame-truss combination; Outrigger truss; "Tie-down" truss	33.3	8.3	25.0	16.7					16.7			
1d-Tubular structures	26.3	5.3	26.3	15.8				5.3	21.0			
3 -WIND RESISTANT DESIGN												
3a-Aerodynamically stable building forms	36.4		27.3	27.3					9.0			
4 -SEISMIC DESIGN												
4d-For very large bldgs, ensure appropriate dimensions or seismic subdiv	16.7		33.3	33.3					16.7			
6 -MATERIAL DEVELOPMENT												
6a-Light-weight, high-strength, reinforced concrete	46.2		7.7	7.7				38.4				
7 -FOUNDATIONS												
7b-Preconsolidation	50.0		25.0	12.5								12.5
8 -COMPOSITE STRUCTURE												
8c-Steel and reinforced concrete construction	21.5	14.3	14.3	7.1				7.1	14.3	7.1		14.3
10 -FIRE PROTECTION												
10b-Fire resisting paint	25.0	25.0	25.0	25.0								

Table A5. Benefits of Selected Structural Innovations (Cont.)

INNOVATION	BENEFITS: COST (PCT)	TIME	STRUCTURAL INTEGRITY	DESIGN	AESTHETICS	CONSTRUCTION	QUALITY	REDUCED WEIGHT/HEIGHT	EFFICIENCY	ACCEPTANCE	ENERGY CONSERVATION	OTHER (PCT)
12 -MASS REDUCTION AND INCREASED DUCTILITY												
12a-Lightweight alloys	36.5	9.0	9.0	9.0				36.5				
13 -FLEXIBLE SERVICES												
13a-Interstitial space	14.3			57.1								28.6
14 -PREFABRICATION/INDUSTRIALIZATION												
14a-Large scale prefabricated-pre-finished structural elements	45.5	27.3		9.1			18.1					
14b-Large scale facade elements	37.5	25.0		25.0			12.5					
14e-Post tensioning	28.6		42.8	28.6								
14h-Computer-aided construction	33.3	25.0		8.3		16.7						16.7

Table A6. Constraints of Selected Structural Innovations

INNOVATION	CONSTRAINTS: COST (PCT)	TIME	STRUCTURAL INTEGRITY	DESIGN	AESTHETICS	CONSTRUCTION	RESEARCH NEED	NEW MATERIALS/PROCEDURES	PERSONNEL/TRAINING	ACCEPTANCE	OTHER (PCT)
1 -STIFFNESS IN HIGHRISE BUILDINGS											
1a-Frame-truss combination; Outrigger truss; "Tie-down" truss				50.0					25.0	25.0	
1d-Tubular structures				60.0					20.0	20.0	
3 -WIND RESISTANT DESIGN											
3a-Aerodynamically stable building forms					25.0		50.0		25.0		
4 -SEISMIC DESIGN											
4d-For very large bldgs, ensure appropriate dimensions or seismic subdiv				40.0					20.0	40.0	
6 -MATERIAL DEVELOPMENT											
6a-Light-weight, high-strength, reinforced concrete	20.0		20.0				20.0		20.0		20.0
7 -FOUNDATIONS											
7b-Preconsolidation	20.0	60.0	20.0								12.5
8 -COMPOSITE STRUCTURE											
8c-Steel and reinforced concrete construction	40.0					20.0		20.0	20.0		
10 -FIRE PROTECTION											
10b-Fire resisting paint	37.5		12.5				12.5	12.5	12.5		12.5

Table A6. Constraints of Selected Structural Innovations (Cont.)

INNOVATION	CONSTRAINTS: COST (PCT)	TIME	STRUCTURAL INTEGRITY	DESIGN	AESTHETICS	CONSTRUCTION	RESEARCH NEEDED	NEW MATERIALS/PROCEDURES	PERSONNEL/TRAINING	ACCEPTANCE	OTHER (PCT)
12 -MASS REDUCTION AND INCREASED DUCTILITY											
12a-Lightweight alloys	20.0		20.0				40.0				20.0
13 -FLEXIBLE SERVICES											
13a-Interstitial space	75.0			25.0							
14 -PREFABRICATION/INDUSTRIALIZATION											
14a-Large scale prefabricated-pre-finished structural elements			25.0	50.0						25.0	
14b-Large scale facade elements								25.0	25.0	25.0	25.0
14e-Post tensioning	20.0								60.0		20.0
14h-Computer-aided construction	33.3							16.7	50.0		

Table A7. Benefits of Selected Enclosure Innovations

INNOVATION	BENEFITS: COST (PCT)	TIME	STRUCTURAL INTEGRITY	DESIGN	AESTHETICS	CONSTRUCTION	QUALITY	REDUCED WEIGHT/HEIGHT	EFFICIENCY	ACCEPTANCE	ENERGY CONSERVATION	OTHER (PCT)
3 -SOPHISTICATED DESIGN/EVALUATION PROCEDURES												
3d-Thermal modelling in design	28.6		14.3	14.3							42.8	
4 -REDUCE HIGH-WIND EFFECTS												
4a-Wind resistant design	14.3		85.7									
5 -MINIMIZE RAINWATER PENETRATION THROUGH JOINTS												
5b-Water tighten joints	71.4	28.6										
9 -USE OF COMPOSITE MATERIALS												
9b-Glass fiber reinforced concrete cladding	20.0		40.0	20.0								20.0
10 -USE OF PREFAB MASS WALLS												
10b-Precast concrete wall component	57.1	28.6								14.3		
11 -USE OF MINIMUM MASS SKIN COMPONENTS												
11a-Sandwich panel systems	33.4	11.1	22.2								22.2	11.1
13 -PASSIVE METHODS FOR METHODS FOR MINIMIZING HEAT'G/COOL'G/LIGHT'G												
13a-Building geometry	16.7			16.7						16.7	49.9	
14 -CONSERVE OPERATIONAL ENERGY BY ACTIVE SYSTEMS												
14b-Solar collectors	14.3									14.3	42.8	28.6

Table A8. Constraints of Selected Enclosure Innovations

INNOVATION	CONSTRAINTS: COST (PCT)	TIME	STRUCTURAL INTEGRITY	DESIGN	AESTHETICS	CONSTRUCTION	RESEARCH NEEDED	NEW MATERIALS/PROCEDURES	PERSONNEL/TRAINING	ACCEPTANCE	OTHER (PCT)
3 -SOPHISTICATED DESIGN/EVALUATION PROCEDURES											
3d-Thermal modelling in design	20.0			20.0			20.0				40.0
4 -REDUCE HIGH-WIND EFFECTS											
4a-Wind resistant design	100.0										
5 -MINIMIZE RAINWATER PENETRATION THROUGH JOINTS											
5b-Water tighten joints				33.3					66.7		
9 -USE OF COMPOSITE MATERIALS											
9b-Glass fiber reinforced concrete cladding			25.0							25.0	50.0
10 -USE OF PREFAB MASS WALLS											
10b-Precast concrete wall component							33.3			33.3	33.4
11 -USE OF MINIMUM MASS SKIN COMPONENTS											
11a-Sandwich panel systems				33.3						33.3	33.4
13 -PASSIVE METHODS FOR METHODS FOR MINIMIZING HEAT'G/COOL'G/LIGHT'G											
13a-Building geometry				100.0							
14 -CONSERVE OPERATIONAL ENERGY BY ACTIVE SYSTEMS											
14b-Solar collectors	33.3						33.3				33.4

Table A9. Added Innovations

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

BOSTI

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

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BUFFALO ORGANIZATION FOR SOCIAL AND TECHNOLOGICAL INNOVATION INC 1479 HERTEL AVE BUFFALO N Y 14216 716-837-7120

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
2. Time
3. Structural Integrity
4. Design
5. Aesthetics
6. Construction
7. Quality
8. Weight/Height
9. Efficiency
10. Research Needed
11. New Materials Needed
12. Training Needed
13. Acceptance
15. Other
20. Energy Conservation

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

	STRUCTURAL AND ENCLOSURE SYSTEMS INNOVATIONS			ENCLOSURE SYSTEMS INNOVATIONS ONLY
	BENEFITS AND CONSTRAINTS	BENEFITS ONLY	CONSTRAINTS ONLY	BENEFITS ONLY
CODING	1-6	7	10	20
CATEGORY	13	8	11	
NUMBER	15	9	12	

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

<u>Benefits</u> - These answers stated that the proposed innovation would increase the building's strength, structural integrity or durability <u>or</u> 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.

<u>Constraints</u> - These responses stated that the proposed innovation would decrease the building's strength, structural integrity or durability <u>or</u> 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

<u>Benefits</u> - 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."

<u>Constraints</u> - 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 la, Trusses, one respondent wrote: "The architectural design must include provisions for a clean and regular frame, truss structural system."

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 Weight/Height	<u>Benefits</u> - 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	<u>Benefits</u> - 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	<u>Constraints</u> - 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	<u>Constraints</u> - 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	<u>Constraints</u> - 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.

13.	Acceptance	<u>Benefits</u> - 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).
		<u>Constraints</u> - 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 (Applied to Enclosure only)	<u>Benefits</u> - 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.

Tt 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 <u>not</u> assigned separate identification codes. Therefore, all of the first listed added innovations are coded with the same identification number, and so on.

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11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

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.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

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

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