Retrofit Wall System for Insulation and Lead Encasement in Older Multifamily Housing

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ABSTRACT

This paper presents an approach to modernization or rehabilitation of buildings with uninsulated masonry walls that have lead-based paint hazards or deteriorated plaster walls. The approach provides a solution to lead contamination on the walls, increased energy efficiency, and comfort improvements associated with better insulated building envelopes. The system sheaths or replaces damaged or contaminated walls with a tight, well-insulated, durable interior surface. The costs of this system are estimated to be less than those of other insulated wall systems. Modeling of the impact of this system shows significant improvement in energy performance. The energy savings over the life of this durable system contribute to significantly offset the oftentimes sizeable cost of lead hazard remediation.

INTRODUCTION

Much of the older multifamily housing stock in the U.S. was built with uninsulated masonry walls coated with interior plaster. After years of use, the plaster walls may have deteriorated. If the walls are badly deteriorated, lead from lead-based paint can freely enter the living space. The condition of the existing wall determines the appropriate mitigation strategy to use. Walls in good condition are frequently encapsuled. Walls with deteriorated plaster, or flaking paint, can be sheathed to encase the lead hazard. Severely damaged walls are typically replaced, as in substantial or gut rehabilitation.

A composite wall system was developed to address the problems of uninsulated, lead-contaminated, masonry walls. The system sheaths damaged walls or replaces deteriorated plaster by adding a tight, well-insulated, durable interior surface. The costs of this system are estimated to be less than those of other insulated wall systems. Modeling of the impact of this system shows significant improvement in energy performance.

Existing Conditions

In many parts of the United States, the older multifamily housing stock includes structures with uninsulated masonry walls. These structures include two- and three-story walk-up apartments, larger apartment complexes, and public housing (both high-rise and townhouse). In much of this older multi-family housing, years of heavy use have left the plaster walls marred or damaged. Long-term building settlement or movement has cracked the plaster, sometimes severely. Repair of severely damaged plaster walls requires replacement or sheathing. Moisture from unvented kitchens and baths has caused condensation on uninsulated exterior walls. At best, this condensation has left stains on the paint or wallpaper. At worst, it has supported mold and mildew growth, fouling the air and creating unhealthy living conditions. Wet walls also lead to deteriorated plaster and flaking paint.

Lead Contamination and Hazard

If the walls in older multi-family housing are badly deteriorated, lead can freely enter the living space. The U.S. Department of Housing and Urban Development (HUD) has recognized the presence of flaking, lead-based paint in older (pre-1978) housing as a major public health concern (Jacobs 1996a, 1996b). Children can suffer permanent mental handicaps and psychological disorders if they are subjected to elevated levels of lead, while adults can suffer hypertension and other maladies. A frequently used definition for elevated blood levels is 20 ug/dL. At this level or above, medical evaluation and environmental intervention are recommended by the Centers for Disease Control (CDC). Moreover, the CDC

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reduced the "intervention level" for childhood lead poisoning to 10 ug/dL in October 1991 and recommended various counseling, monitoring, and community-wide prevention activities at levels between 10 ug/dL and 19 ug/dL (HUD 1995). The U.S. Environmental Protection Agency (EPA) has estimated that approximately 64 million homes in the U.S. have some lead-based paint (EPA 1995).

In the private housing market, testing for the presence of lead is not common. Instead, inspection for lead hazards is only initiated when children are identified with elevated levels of blood lead. However, since December 1996, HUD and EPA regulations require that sellers and landlords of residential properties disclose known lead-based paint and lead-based paint hazards. In addition, buyers and renters of housing are given a 10-day period to conduct a lead-paint inspection or risk assessment at their own expense.

Lead Paint Hazard Remediation

The threshold levels at which paint is considered contaminated by lead are 1 mg/cm^2 or 0.5% by weight (HUD 1995). Most paints used for residential, commercial, and institutional properties prior to the mid-1940s had high lead content with some oil-based paint as high as 50% by weight (HUD 1995). The paints most widely used between the mid-1940s and 1978 tended to have lower lead content but were still well above the threshold levels identified above.

Four remediation strategies are used to mitigate the hazard associated with lead-based paint. These are component replacement, paint removal, enclosure/encasement, or encapsulation. The advantages and considerations for each strategy are presented in Table 1.

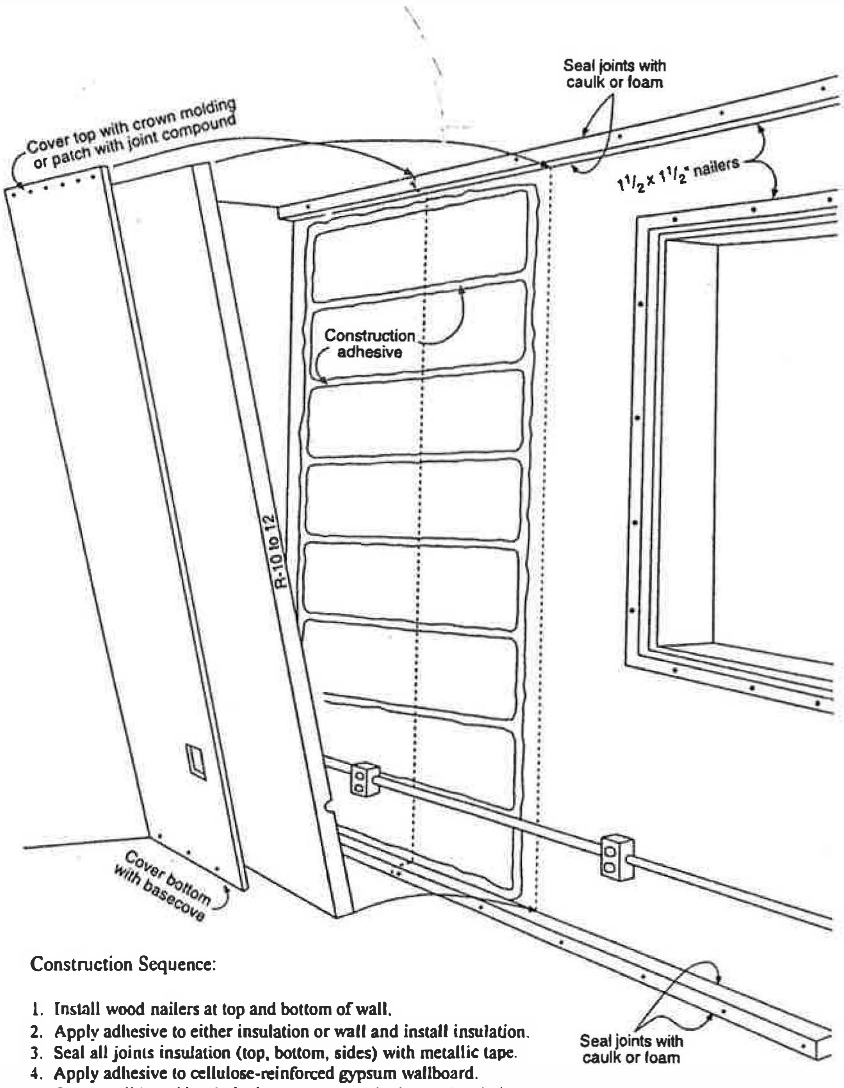
For walls, the condition of the existing wall will often determine the strategy used. If the wall plaster and paint are in good condition, encapsulation is frequently used for cost reasons. Since encapsulation relies on adhesives that bond to the existing paint, its durability is dependent on the substrate coating. Therefore, encapsulation is viewed as an inferior solution to enclosure (see Table 1). If the wall is structurally sound but the plaster is damaged or deteriorated or if the paint is flaking, enclosure or encasement can provide both an acceptable finished surface and control of the lead hazard.

TABLE 1

Lead Based Paint (LBP) Abatement Techniques for Walls

Lead Paint Abatement Techniques	Advantages	Considerations
Component Replacement	High level of protection from LBP hazard No follow-up monitoring required Quick and easy to implement Opportunity for energy conservation measures	Can raise lead dust Historic preservation issues Can generate hazardous waste
Paint Removal	Removes lead permanently Appropriate for many surfaces Appropriate for historic preservation sites Often costs less than component replacement	Can create airborne hazards Clean-up can be costly Some methods are weather dependent Damaged substrate create problems Costly for large areas Can be very hazardous to workers
Enclosure	Costs less than component replacement Easy to install Works well with large surfaces Can be used in many friction surfaces Installation creates little lead dust Opportunity for energy conservation measures Can be used on interior & exterior surfaces	LBP is not removed Monitoring required to ensure system integrity Not appropriate if substrate is not stable Disclosure of LBP required May be slower than component replacement Historic preservation issues
Encapsulation	Relatively inexpensive Easy to apply Generates little dust Appropriate for interior & exterior surfaces Minimal hazardous waste	LBP not removed Not appropriate for friction surface Durability dependent on condition of surfaces Encapsulation must be monitored Disclosure required Long-term effectiveness is unknown

Source: HUD 1997.



Construction Sequence:

1. Install wood nailers at top and bottom of wall.
2. Apply adhesive to either insulation or wall and install insulation.
3. Seal all joints insulation (top, bottom, sides) with metallic tape.
4. Apply adhesive to cellulose-reinforced gypsum wallboard.
5. Offset wall board by six inches from vertical joints in insulation.
6. Place wallboard on shims and press into place.
7. Mechanically fasten the top edge of the wallboard to the nailer.
8. Remove the shims and allow the wallboard to hang straight.
9. Mechanically fasten the bottom edge of the wallboard.
10. Finish the wall in accordance with standard practice.

Figure 1 *Construction of the composite wall is simple and straightforward.*

Enclosure fastens mechanically to the structure and can be expected to last at least 20 years (HUD 1995). If the wall is severely damaged or is structurally unsound, replacement provides both an acceptable interior finish and lead elimination. Paint removal is not generally considered an economically viable option for walls with their large surface area. The composite wall system can be used for both enclosure/encasement and plaster replacement strategies.

Existing Energy Costs

High space-conditioning costs and uncomfortable living conditions result from inadequate insulation in the walls. Older multifamily housing may also contain old, low-efficiency furnaces or boilers that further escalate the space-conditioning costs. Space heating costs in the range of $800-$1000 per year are common for typical (1000 ft^2), older, multifamily dwelling units in Chicago, Illinois. Dealing with these problems offers opportunities, not only for improving the health and comfort of the occupants, but also for improving the energy performance of the units.

COMPOSITE WALL SYSTEM

Development

To address the problems of uninsulated masonry walls painted with lead-based paint, a composite wall system has been developed to sheath deteriorated plaster and encase the lead paint hazards on wall surfaces while adding a tight, well-insulated, and durable interior surface to perimeter walls. This lower-cost wall system is a result of DOE-funded research and development conducted at two national laboratories. In addition to the laboratories, a collaborative effort to demonstrate and field test the system included a public housing authority and the materials manufacturers.

Description. The wall system includes cellulose-fiber-reinforced gypsum wallboard, foil-faced polyisocyanurate insulation, a one-component polyurethane foam with limited expansion to bond the components together, metallic tape to seal joints in the insulation, and wood nailers and fasteners to mechanically fasten the top and bottom of the system to the existing masonry wall. Figure 1 illustrates the construction of the composite wall. In addition to providing insulation and lead encasement, the foil-faced insulation and sealed joints provide an effective air and moisture barrier in the wall. This barrier will also help to reduce moisture and condensation problems.

Prototype Testing. A prototype wall was constructed and tested at the Chicago Housing Authority's headquarters building with materials and labor provided by manufacturers.

In order to assess the durability of the system, the prototype wall was subjected to impact testing. The wall was subjected to the ASTM standard drywall impact test and performed significantly better than typical wall construction of paper-faced drywall supported on 2×4 wood studs and insulated with fiberglass. "Failure" on the composite wall was a small hairline fracture that was easily repaired with drywall compound. "Failure" of typical wall construction would require removal of the broken drywall, replacement with a new piece, and extensive patching with tape and drywall compound. The prototype wall also was subjected to hammer blows, as shown in Figure 2.

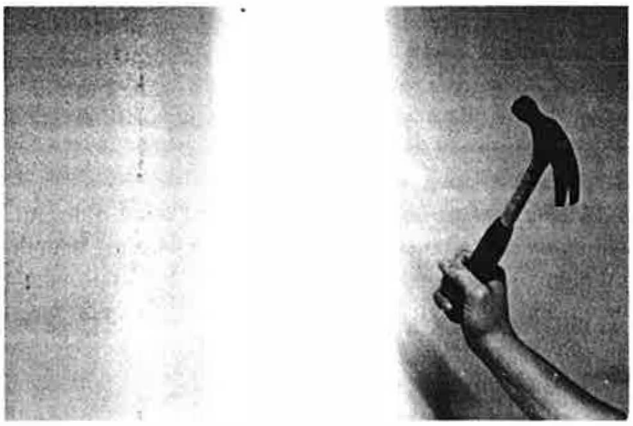


Figure 2 *The prototype composite wall was subjected to impact testing to determine how well it would withstand the impact and what would be required to repair the wall. Here a hammer blow has left a dimple in the wallboard joint. Unlike common drywall, there was no "breakthrough" on the back. Repair involved simply filling the dimple with joint compound.*

Figure 3 *A Public Housing Authority unit was rehabilitated with the installation of an innovative composite wall system. This system undid years of hard use followed by extended vacancy and major moisture damage. High moisture levels from a leaky steam heating system had combined with uninsulated masonry walls to destroy the exterior wall lath and plaster finish.*

Field Testing. Subsequently, the system was field tested in an unoccupied unit of the Brooks Homes of the Chicago Housing Authority (CHA); see Figures 3 through 5.

Projected Energy Performance

Two typical units belonging to the CHA were selected and their building components were entered into a residential energy analysis software tool. The existing perimeter wall system was modeled first, and anticipated energy consumption and annual costs were calculated. Then, four potential wall systems were modeled using the energy analysis software, and anticipated energy consumption and annual costs were calculated again.

A two-bedroom end unit townhouse and a three-bedroom interior unit townhouse were selected for energy analysis because they could be considered "typical units." The housing authority's units ranged from one- to four-bedroom units, and there were both garden units and townhouses. Townhouses were used because there might be a variation in energy usage between first and second floor garden units, while a two-story townhouse would be more representative of the typical building unit heat loss.

Units used in the energy analysis are being renovated by the housing authority. Existing lath and plaster has deteriorated to the extent that it must be sheathed or removed and replaced. The four wall systems modeled are possible remedies for the existing plaster walls.

Information about the units was gathered from blueprints and entered into the software (e.g., unit dimensions, building material components and configuration, heating system, etc.). Demolition drawings of existing units lacked some details

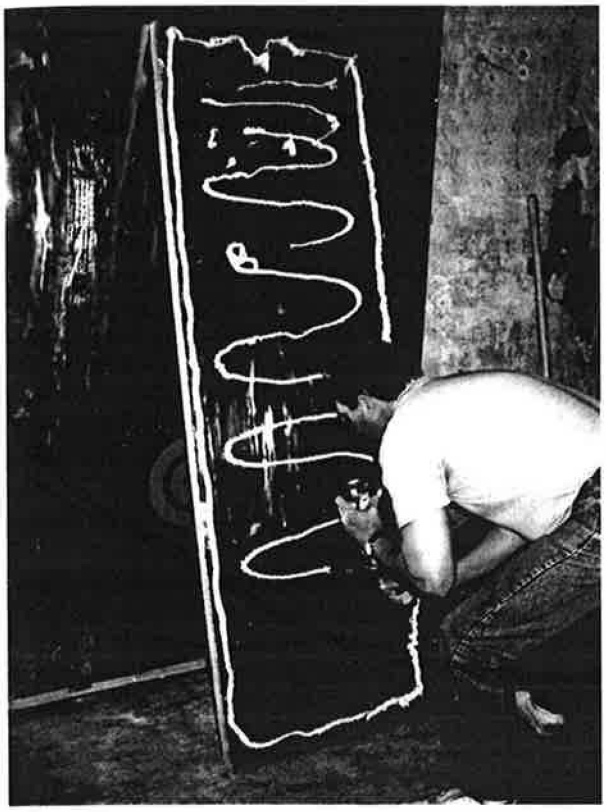


Figure 4 *Polyurethane foam adhesive was used to fasten 1½ in. thick rigid foam insulation to the interior surface of the walls. The exterior wall insulation used was a polyisocyanurate insulation with foil facers and an R-12 rating (1½ in. thick). Foam adhesive and drywall screws fasten the ½ in. thick cellulose-reinforced gypsum wallboard to previously installed 2 × 2 wood nailers (top and bottom) and to the rigid foam insulation.*

about dimensions. Footprints of existing units shown on demolition drawings were changed in renovated units on construction drawings. Materials and sizes of existing doors and windows were not shown on demolition drawings, but construction drawings showed materials, sizes, and locations of new windows and doors on construction drawings.

Demolition drawings do show that the existing units have brick veneer and CMU block exterior walls with lath and plaster interior. The ceiling/roof and floor are five-inch-thick concrete and the crawl space is uninsulated. The heating system is a fuel-fired hydronic distribution system. Planned renovations to the existing units include the addition of double-pane vinyl windows and steel-polyurethane core exterior doors. Construction drawings also show the addition of a gabled roof with shingles and R-30 insulation between the existing concrete ceiling/roof and the new gabled roof.

The two-bedroom and three-bedroom units were first modeled in the energy analysis software with walls as they existed prior to renovation (block, brick, and plaster walls). All other building features were entered according to the construction (not demolition) drawings. For example, R-30 insulation was entered along with the concrete ceiling and gabled roof. Double-pane vinyl windows and steel-polyurethane core doors were entered. The units' square footage and exterior wall areas were taken from construction drawings. Infiltration was estimated to be 0.40 ACH natural for all scenarios. Since construction drawings showed no modification of floors, five-inch concrete floors with uninsulated crawl space were entered into the energy analysis software.

Then additional simulations were conducted introducing only the four proposed wall systems. These wall systems were (1) a composite wall system using polyisocyanurate (R-12) insulation and cellulose-reinforced gypsum wallboard; (2) a composite wall system using extruded polystyrene (R-7.5) insulation and cellulose-reinforced gypsum wallboard; (3) a wall system using 2× 4 wood studs at 24 inches on center, batt insulation (R-13), and ½ inch gypsum drywall; and (4) a wall system using 1½ inch "Z" furring, 1½ inch batt insulation, and ½ inch gypsum drywall. (The wall system that used "Z" furring is the one currently in use on the renovation project.) All other building features and dimensions were kept the same for the four additional analyses so that the only variables in building features or dimensions were the various wall systems themselves.

Wall R-values are based on the following assumed R-values: brick, 1.20; block, 1.85; air gap (in existing only), 0.80; plaster, 0.15; 1½ inch polyisocyanurate, 12.00 (per manufacturer); ½ inch drywall, 0.45; 1½ inch EXPS, 7.5; Z furring and 1½ inch batts, 2.00; 3½ inch, R-13 batts, 13.00; 2 × 4 wall studs, 4.38; inside air film, 0.68; outside air film, 0.17 (Kosny 1998; ASHRAE 1997).

The analyses were also modeled using two different utility rates: the actual housing authority utility rate and the local private residential utility rate. Table 2 shows anticipated annual consumption and utility costs associated with the exterior walls of the selected units. The annual consumption and

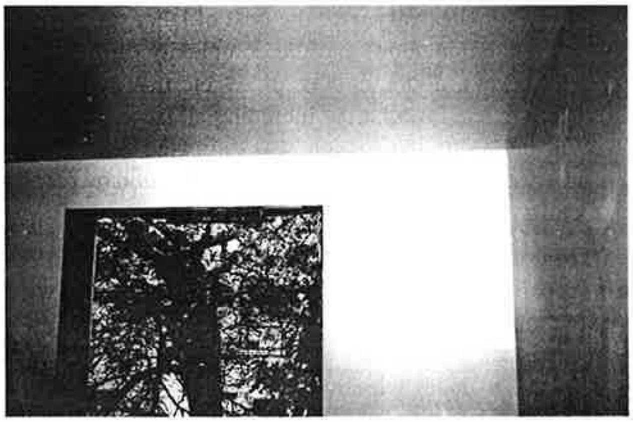


Figure 5 *Conventional drywall finishing techniques and painting are used to finish the composite wall system. The completed installation has returned the interior to "like new" condition.*

TABLE 2
Thermal Analysis of Wall Systems

	Consumption		Cost	
			Housing Authority	Private Residential
Wall System	MBtu/yr	MJ/yr	Rate, $/yr	Rate, $/yr
2 BR End Unit				
Existing Wall (Uninsulated Masonry)	28.3	29,850.80	107	158
Composite Wall with R-12 1 1/2" Polyiso.	8.5	8,965.80	32	53
Composite Wall with R -7.5 1 1/2" EXPS	11.7	12,341.20	44	71
2 x 4s with 3 1/2" Batts	8.9	9,387.70	34	55
"Z" Furring with 1 1/2" Batts and Drywall	21.7	22,880.20	82	125
3 BR Interior Unit				
Existing Wall (Uninsulated Masonry)	19.6	20,674.10	74	113
Composite Wall with R-12 1 1/2" Polyiso.	5.9	6,223.30	22	36
Composite Wall with R -7.5 1 1/2" EXP	8.1	8,543.90	30	49
2 x 4s with 3 1/2" Batts	6.2	6,539.80	23	38
"Z" Furring with 1 1/2" Batts and Drywall	15.0	15,822.00	57	89

utility costs are for heat loss through exterior walls only and should be used for comparison between proposed wall systems. These values do not reflect total energy consumption for the whole housing unit since the wall systems are the only components being compared. This information is used in the discussion section to evaluate the life-cycle costs of the various options.

Estimated Construction Costs

The actual costs of this system have not yet been fully defined because it has not seen widespread application. Contractor estimates vary with the cost of labor (geographically and union/nonunion) and the complexity of the actual project (windows, doors, outlets, pipes, etc.). A moderately complex complete installation, including all labor, materials, overhead, and profit, in Chicago, was estimated to cost $3.59 per square foot of wall (1997) based on installation by professional craftsworkers.

The cost estimate in Table 3 was prepared using 1996 Means repair and remodeling cost data. Cost multipliers were added for the Chicago area and 2% was added for 1997 inflation to estimate 1997 costs. Cost estimates do not include modifications to doors, windows, or door and window frames. All wall sheathing options require this modification and the costs were assumed to be similar. The conventional wall system would typically require equal or more expensive modifications to door and window frames due to the greater additional wall thickness. In the traditional wall system, four inches is added to the wall thickness, while the composite or Z furred wall systems add only two inches.

Table 3 shows the comparative costs of the composite system and other systems. Because of the higher cost of polyisocyanurate insulation, a comparable system substituting extruded polystyrene was estimated. This lowered the initial cost to $3.31 per ft^2 ($35.63 per m^2) while also reducing the overall R-value of the wall (see "Discussion" for life-cycle cost impact). The two other systems shown in the table reflect common practice in Chicago. The 2×4s and fiberglass system ($3.69 per ft^2 [$39.72 per m^2]) is common in scattered site housing rehabilitation. The metal Z furring and fiberglass system ($3.99 per ft^2 [$42.95 per m^2]) was used on a recent housing authority rehabilitation project.

Given the simplicity of the composite wall system, it is believed that this system is within the capabilities of resident labor crews for public housing developments. The composite wall system is attached directly to the existing wall with furring at the top and bottom and with adhesive. This system uses fewer pieces of material than a conventional wall system. The composite wall system requires less precision in assembly. The use of semi-skilled labor could significantly reduce the labor costs while providing job experience for public housing residents.

DISCUSSION

The use of the composite wall system as an acceptable, long-term (20 years+) means of encasing lead paint hazards on walls was demonstrated in the field testing at the housing

TABLE 3

Cost Estimates for Wall Systems Based on R.S. Means Estimating Guides for Chicago, IL in 1997

Composite Wall System with Polyisocyanurate			(Clear Wall R-16.4)		
Item	**Material**	**Labor**	**Total**	**w/O and P**	**w/O and P**
Furring (1-1/2" [3.8 cm] at t. and b.)	$0.05	$0.12	$0.17	$0.26	$2.80
Polyisocyanurate (R-12) w/adhesive	0.62	0.34	0.96	1.22	13.13
Fiberboard w/ adhesive, taped and finished	0.36	0.51	0.87	1.29	13.89
Paint (primer + 2 coats)	0.05	0.35	0.40	0.61	6.57
4" (10.2 cm) base, vinyl	0.06	0.10	0.16	0.21	2.26
Total			$2.56	$3.59	$38.64
Composite Wall System with EXPS			**(Clear Wall R-11.9)**		
Item	**Material**	**Labor**	**Total**	**w/O and P**	**w/O and P**
Furring (1-1/2" (3.8 cm) at t. and b.)	$0.05	$0.12	$0.17	$0.26	$2.80
EXPS 1-1/2" (3.8 cm), (R-7.5) w/ adhesive	0.48	0.26	0.74	0.94	10.12
Fiberbond w/ adhesive, taped and finished	0.36	0.51	0.87	1.29	13.89
Paint (primer + 2 coats)	0.05	0.35	0.40	0.61	6.57
4" (10.2 cm) base, vinyl	0.06	0.10	0.16	0.21	2.21
Total			$2.34	$3.31	$35.63
2x4s and Fiberglass Batts			**(Clear Wall R-16.1)**		
Item	**Material**	**Labor**	**Total**	**w/O and P**	**w/O and P**
2 x 4s (5.1x10.2 cm), 24" (61.0 cm) o.c.	$0.37	$0.49	$0.86	$1.21	$13.02
Batt Insulation (R-13)	0.23	0.16	0.39	0.51	5.49
1/2" (1.3 cm) Drywall, taped and finished	0.22	0.51	0.78	1.15	12.38
Paint (primer + 2 coats)	0.05	0.35	0.40	0.61	6.57
4" (10.2 cm) base, vinyl	0.06	0.10	0.16	0.21	2.26
Total			$2.59	$3.69	$39.72
Metal "Z" Furring and Fiberglass Batts			**(Clear Wall R-6.4)**		
Item	**Material**	**Labor**	**Total**	**w/O and P**	**w/O and P**
"Z" Furring	$0.19	$0.79	$0.97	$1.52	$16.36
1-1/2" (3.8 cm) Batt Insulation	0.10	0.16	0.26	0.34	3.66
6 Mil Poly Vapor Barrier	0.04	0.07	0.11	0.16	1.72
1/2" (1.3 cm) Drywall, taped and finished	0.22	0.51	0.78	1.15	12.38
Paint (primer + 2 coats)	0.05	0.35	0.40	0.61	6.57
4" (10.2 cm) base, vinyl	0.06	0.10	0.16	0.21	2.26
Total			$2.68	$3.99	$42.95

Note: Costs are in $/SF of wall, except the last column, which is in $/SM of wall.

authority. Testing also demonstrated the impact resistance and ease of repair of the composite wall system. The energy performance of the composite wall is estimated to be significantly better than the existing uninsulated walls. The energy performance is comparable or superior to that of commonly used retrofit insulation techniques. The composite wall system reduces living space by 1% to 1.5%, while the thicker alternative sheathing methods cause approximately a 3% reduction.

The estimates of initial costs of the composite wall system indicate that they are below the cost of the commonly used retrofit wall and insulation systems. Given the lower initial cost, energy performance, durability, and ability to effectively encase lead-paint hazards, the composite system appears to have broad potential application in the U.S.

However, as can be seen by the payback analysis shown in Table 4, the system cannot be justified on the basis of energy savings alone. This is also true of the other potential retrofit options as well. The retrofit of insulation to uninsulated masonry walls is cost justified only when other factors such as lead hazard abatement or deteriorated plaster dictate improvements to the wall. Under these circumstances, the incremental cost of including insulation is usually easily offset by the energy savings within the service life of the insulation (8 to 10 year payback).

CONCLUSIONS

The composite wall system has been demonstrated to provide an effective means to sheath or replace existing lead paint-contaminated or deteriorated plaster on uninsulated masonry walls. The estimates of cost for various alternatives indicate that the composite wall system has the lowest initial cost. The demonstrated resistance to damage and ease of repair indicate that the composite wall system should have low maintenance and repair costs throughout its life. Energy consumption and cost analysis indicate that the composite wall system will significantly reduce energy consumption compared with uninsulated masonry walls. However, energy savings alone cannot cost justify the installation of this system. The composite wall system is cost justified when solving multiple problems, such as lead paint contamination, deteriorated plaster, condensation on the wall, cold walls, and high energy consumption.

The important challenge that faces renovators of multifamily housing is to include energy conservation measures whenever the opportunity presents itself. In addressing any of the many problems that can occur with the exterior walls of older multifamily housing, it is prudent to use those measures that will enable the occupants to lower their energy bills as well.

ACKNOWLEDGMENTS

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The software used in the simulations was *REM/Design*, Version 8.2, a product of the Architectural Energy Corporation of Boulder, Colo.

TABLE 4
Construction Cost, Energy Cost Savings, and Simple Payback or Various Wall Systems

Wall System	Total Construction Cost ($)	Energy Cost Savings Per Year ($)		Simple Payback (years)	
		HA	Resid.	HA	Resid.
Composite Wall (Polyiso.)					
2-BR (777 S.F; 72 S.M.)	2789	75	105	37.2	26.6
3-BR (538.5 S.F; 50 S.M.)	1933	52	77	37.2	25.1
Composite Wall (EXPS)					
2-BR	2572	63	87	40.8	29.6
3-BR	1782	44	64	40.5	27.8
2x4 and Fiberglass Batts					
2-BR	2867	73	103	39.3	27.8
3-BR	1987	51	75	39.0	26.5
Metal "Z" Furring and Fiberglass Batts					
2-BR	3100	25	33	124.0	94.0
3-BR	2149	17	24	126.4	89.6

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