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SUB-SLAB DEPRESSURIZATION DEMONSTRATION IN POLK COUNTY, FLORIDA, SLAB-ON-GRADE HOUSES

by:

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ABSTRACT

Six slab-on-grade houses in Polk County, Florida, with indoor radon levels between 19 and 80 pCi/l were mitigated using sub-slab depressurization systems. With the compacted, moist soil fill under the slabs, sufficient sub-slab communications were difficult to establish. Increasing the suction pit size and using more powerful fans improved the strength of the pressure fields within 3 to 8 m of the suction holes but did little to extend them beyond this radius. The most effective means for extending the field was found to be installing additional suction holes (depressurized by the same fan) in locations where the pressure field was the weakest. Suction holes were placed both in centralized and in near-perimeter locations reached either by interior slab holes or through holes in the exterior stem wall. Indoor radon levels were measured using 2-day charcoal canisters, continuous radon monitors, and long-term (3 mo-1 yr) alpha track detectors.

This paper has been reviewed in accordance with the U.S.Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.

INTRODUCTION

This research program was designed to demonstrate or develop techniques which, at low to moderate cost, will have a high probability of producing average long-term (3 months or more) radon levels in 8 preselected slab-on-grade houses in the Polk County, Florida, area within the proposed USEPA guidelines of 4 pCi/l. Six of the houses have had mitigation systems installed to date. The slabs are typically laid on a tightly compacted soil matrix that may have relatively low permeability to soil gas flow. The permeability may be further reduced by the presence of water in the soil pores occurring because of the relatively shallow ground water table and seasons of high rainfall. Either or both the native soil and the fill material can contain elevated concentrations of radium if its source was a mineralized (phosphate) area or residue or tailings from phosphate mining (1) Since the slab (floor) itself rests directly on this soil, any opening in the entire foundation structure has the potential to be a conduit for soil gas, and thus radon, entry. The major routes of soil gas entry are leaks around pipes, vents, and connections to floor based fixtures such as toilets, showers, and baths, or cracks in the slab itself, and through the concrete blocks. The driving force believed to pull radon through these entry routes is the pressure gradient between the inside (usually lower) and the outside. The situation of a slab directly overlying a soil matrix with no conducting aggregate is somewhat analogous to that found beneath basement slabs in other areas, such as Sweden (2) and some areas of the U. S.

The purpose of this paper is to review some of the variations of sub-slab depressurization design features that were investigated in the light of their impact on extending a pressure field under a slab. After a review of some of the procedures employed in house selection and mitigation, the effects of some of the more important variations and the results to date of their implementation will be discussed. Finally some of the conclusions that can be drawn at this point will be explored.

PROCEDURE

The houses for this demonstration were selected from a group of 22 homes identified from earlier surveys (3) as being likely to have elevated radon levels. These 22 houses in Polk County, in the vicinity of Lakeland, Bartow, or Mulberry, Florida, were visited and subjected to a series of diagnostic tests which included: 1. house characterization, 2. sub-slab communication tests, 3. radon grab and sniffer measurements, 4. infiltration tests using fan doors to quantify the leakage area in the house construction, 5. a gamma ray survey of the house and surrounding lot site, 6. two day integrated indoor radon measurements using charcoal canisters, and in some houses, 7. a soil gas and permeability survey, and 8. soil radium measurements. Tests 1 and 6 were used primarily for screening purposes; while 2, 3, and 4 were more useful in designing mitigation plans. The remainder, 5, 7, and 8, provided background information. The houses selected were all slab-on-grade houses with single slabs that were thought to be representative of the existing houses in the area and of those in South Florida in general.

The data obtained during the diagnostic visit were used to develop detailed mitigation plans for each house. Although other mitigation strategies were considered, the project was defined to be primarily a sub-slab depressurization (SSD) demonstration with a variety of approaches and applications. Some of the variations on the theme of SSD included varying the suction pit size, tunneling under the slab to try to extend the pressure field from single holes, sealing air entry leaks, using different sizes of fans, and increasing the number of suction holes. Table 1 lists the eight houses selected for this demonstration project and the mitigation schemes that have been planned or installed to date.

Another variation that was touched by this study but which still needs further investigation is that of location of the suction hole. Specifically, an unresolved question is whether a centrally located suction hole has a greater probability of extending its pressure field in all directions or if a suction pit located near the perimeter of the structure is more likely to take advantage of settling of the fill material near the stem wall as a manifold to extend the pressure field's influence. In this respect Florida housing is different from the more typical U. S. housing stock. In central Florida, the sub-slab soil is generally a 0.5 m layer of back fill. Elsewhere, if aggregate is not used for drainage, the sub-slab soil is usually somewhat undisturbed native soil.

SUB-SLAB DEPRESSURIZATION VARIATIONS

One of the diagnostic measures used to predict the success of a SSD strategy is the sub-slab communication or pressure field extension. Therefore, in installing the test systems, measurements of the sub-slab pressure field were made for each of the various steps or modifications tried to see what techniques offered the best chance of reducing radon infiltration. At houses B2, B11, A3, and B8 the effect of increasing the pit size under the initial suction hole on the pressure field generated was examined. As can be seen from Figure 1 (for house B11), increasing the hole size had an impact on the strength of the pressure field within 5 m of the suction hole but had much less to no effect at greater distances. This observation agrees with the reported calculations of Ericson et al. (2). However, there was reasonable evidence that the soil permeability was not isotropic and that air passages were even blocked by the excavation process, so even distribution of the pressure field cannot be assumed.

Radon levels in the first two houses (B2 and B11) were not sufficiently reduced by the single central suction points, presumably related to the failure of the pressure fields to be extended adequately. Efforts were made to improve the extension by drilling through the exterior stem walls near areas beyond the effective pressure fields and excavating tunnels from the slab edges toward the suction pits. In neither house were the tunnels able to be extended far enough (or aimed accurately enough), to connect to the central suction pits. Although there seemed to be some measurable difference in the extended pressure fields, it did not seem to be significant and there was little change in indoor radon levels. Because these efforts were very time and labor intensive and produced such marginal results, no further tunneling was attempted.

At houses B11 and B8 smoke was observed to enter the crack at the perimeter of the garage slab where it adjoined the stem wall to the house slab. This entry was verified to be due to the fact that the sub-slab system suction holes were within two meters of the walls. Caulking this crack with 1-part urethane sealant resulted in a significant increase in the pressure field, especially at points close to the suction pit. As with varying pit size, more distant points seemed unaffected. Later the exterior cracks around the bases of the toilets in house B2 were sealed. Although no immediate significant change was measured in the pressure field extension, this action may have contributed to some measurable reductions in indoor radon. These experiences highlight the importance of sealing outside openings that could limit the extension of a pressure field under a slab by allowing airflow or interior openings that could be possible radon entry routes.

Although increasing hole size and sealing cracks did improve the pressure field distributions under the slabs, they did not extend it sufficiently. More powerful fans were temporarily installed to induce greater pressure differentials at the suction point in houses B2 and B8. Limited time precluded measuring any additional radon reductions achieved. However, the impact on the strength of the sub-slab pressure field was measured at the test holes. At house B2, the original 1.9 in WC static pressure (SP) fan was compared with 2.3 in WC and 6 in WC SP blowers and a vacuum cleaner (33 in WC SP). Figure 2 shows the results with these four devices represented by the square, the plus, the diamond, and the triangle, respectively. As can be seen, the effect is very nearly linear. If the suction is increased by a factor of three at the suction point, about a three-fold improvement is made at the test holes. However, again it appears that while the pressure field is improved at the near test holes where communications were already established, any enhancement of the pressure field beyond about 5 m is difficult to measure with confidence. In theory, at least, increasing the suction at a single suction point enough should generate a strong and extensive enough pressure field under the slab to prevent soil gas entry. However, this method is probably not as stable in the long run as installing additional suction points would be. If a system were depending on a 20 or 30 in WC ΔP at a single suction hole the performance could be dramatically reduced if cracks in the slab or sealant failure occurred over the years.

By measuring the flow rates in the exhausts when different pressure differentials were induced at the suction point of house B2, it was possible to generate the "system" curve for the ΔP airflow characteristics of the fill material under the slab shown in Figure 3. This is a very flat curve compared to the system curve for 30 m of 4-in pipe, indicating much greater flow resistance. Very little air moves through the soil under the slab even at large ΔP. It is for this reason that smaller than 4-in diameter pipe can be used in the sub-slab systems when sand (usually rather wet) is under them. Because of the high resistance to airflow the centrifugal blowers installed were operating near their static limits - pulling almost maximum pressures at low airflows. Some of the fans became hot during the warmest part of the day because not enough air was moving to cool the motors when the surrounding air in the attic was too hot to cool them sufficiently. While introducing a leak would provide more air for cooling, it would weaken the pressure field. A better method would be to try to find a blower that could move 10 to 15 cfm at a ΔP of 4 to 5 in WC so that there is enough airflow to cool the blower and the ΔP at the suction points will be increased to 2 to 4 in WC.

Since increasing the fan size did not extend the range of the pressure field significantly (though it did in magnitude at close points), it was determined to use additional suction points in existing systems at houses B2, B11, A3, B8, and A7 as is indicated in Table 1. This was accomplished using PVC pipe to run from the negative pressure side of the fan in the attic to a suction point located in the floor of closets located at positions in the house distant from the first suction points and where the pressure fields seemed to be the least. In house B11, 4 in PVC pipe and in the other houses 1-1/2 in PVC pipe was used. The smaller diameter pipe could have been used in all cases because of the low flow of air being drawn through the fill and pipes by the blowers. There was little to no measurable pressure loss at the low air velocities encountered. The additional suction points resulted in substantial improvements in the pressure distribution as shown in Figure 4 for house B7. The technique of using more than one suction point with smaller diameter pipe is seen as a good possibility for radon control in existing buildings in Florida. This technique seems to work well because of the airflow characteristics of the fill under the slab (high resistance - low flow). Each suction point produces a somewhat equivalent area of effective coverage; the flow is still low enough that the suction produced is essentially the same at each suction hole; and the small increase in flow that does result is beneficial to fan cooling.

Optimized pressure yields were obtained for all six houses under somewhat similar conditions. Individual plots of those data showed valuable information for each house, but it was hard to generalize the information across the houses because of the differences of test hole locations, the variability of the ranges of magnitudes encountered, and the heterogeneity of the fill material. Therefore a composite plot of the pressure fields for all six houses is shown in Figure 5. This representation shows the scatter one would expect from the variety of soils used as fill material, the variability of compaction employed, and the range of moisture contents encountered. However, the plot also reflects consistency to some degree indicating generally good communications inside 3 m, somewhat marginal levels from 3 to 8 m, and generally poor to no pressure field extension beyond 8 m. This evidence suggests that the use of additional suction points beyond these radii may be the best route to pursue in extending pressure fields.

To this point, all of the pressure field discussion has involved effects of controllable variables, such as pit size, fan size, tunnels, or crack caulk. However, the pressure field extensions in some of the houses on as many as five different days with either the same or very similar systems operating in the house were measured. It was evident that other factors outside of the system can have major effects on the performance that may outweigh those of changes to the system. Some of the main differences noted between two days' measurements were higher humidity, shifts in wind direction and/or speed, and rain fall or differences in moisture histories. It was noted during installation of the suction points that the fill material under the slabs were often nearly saturated with moisture. In some of these cases, this phenomenon occurred in areas near the center of the slabs. Because of the occurrence and movement of water under the slabs, the airflow-ΔP characteristics of the fill material seems to change with moisture patterns.

RADON REDUCTION

The effects of implementing the mitigation strategies described in Table 1 on indoor radon concentrations are summarized in Table 2 where radon levels were determined by integrated short-term (2-day) measurements with charcoal canisters (CC), the average of hourly counts from continuous radon monitors (CRM), and integrated long-term (2-week - 3-month) measurements by alpha track detectors (ATD). Presumably the CC measurements were made under closed house (except for normal entry and exit) conditions. The longer-term CRM and ATD measurements were made under normal living conditions. Therefore, in most cases, the great variation between some of the readings are due to the fact that during the time periods covered by a particular method, the houses were opened or closed to varying amounts. When the CRM was used over most or all of the time a CC or ATD was deployed, agreements over those times are quite good.

As can be seen in Table 2, the radon levels have been reduced to near or below the target level of 4 pCi/l in 5 of the houses (B2, B11, B8, A7, and B3). House A3 represents the most difficult house to show results. Its current level is about 22 pCi/l; the 9.1 pCi/l represents an experimental mode in which the home owner left the air handler fans on for a 2 day period. It appears that this house must have some leaks in the air handling system that provide some dilution of indoor radon and possibly even some equalizing of the indoor pressure exerted. Houses A1 and A4 have been monitored for pre-mitigation purposes but have not had any mitigation installed. Both houses show significant reductions in the spring levels from that measured in the fall. This observation suggests that spring mitigations may not be the best timing to produce reliable results.

CONCLUSIONS AND RECOMMENDATIONS

One guiding principle of this project has been to identify design issues applicable to houses in this area, and to obtain as much information as possible to guide potential mitigators in designing systems for other houses. Summarized below are several issues for this and any follow-on demonstrations.

OPTIMUM DESIGN FEATURES FOR SUB-SLAB DEPRESSURIZATION

Sub-slab depressurization has the potential to be an effective radon mitigation technique in the South Florida slab-on-grade housing stock. However, with the tightly packed sub-slab fill material, it was difficult to extend the pressure field from a single suction hole much beyond 3-8 m. While increasing the suction pit and/or fan sizes and sealing cracks are good enhancements to system performance, multiple suction holes seem to be almost a requirement in order to extend the pressure fields under most of the slab area. The airflow from any one suction pit was low enough that 1-1/2 in diameter PVC or larger was adequate to conduct the air with no perceivable pressure loss to wall friction. Piping several suction holes through the same fan does not seem to reduce the pressure differentials, and is even beneficial to the system as it creates more flow through the fan to help in cooling the motor.

This study has included a limited variation of several design parameters, including suction pit size, number of holes, size of fan, and size of exhaust pipes. One unanswered question still to be resolved concerns the optimal location of the suction holes. Originally it was thought that a central placement was best because a pressure field of a given radius would cover more area than one where part of it may be truncated by a perimeter stem wall. For convenience or lack of more suitable options, some of the first pits were located near or on the perimeters. In some of those cases, greater pressure fields resulted. It is still to be shown whether this was random chance or if perhaps the soil fill nearest the stem wall is generally less well compacted and thereby acts as a manifold to extend the pressure field. Another question is the interaction between sealing and the depressurization system.

WEATHER EFFECTS

The effect of rainfall and other climatic conditions on radon levels and system effectiveness has been noted but not studied in detail. Likewise, fan life may become an issue given the hotter attic temperatures and lower gas flow rates in the houses studied here.

OTHER MITIGATION STRATEGIES

Although sealing of low-level houses and whole house pressurization of tighter houses were originally scheduled for this study, they were not investigated in order to focus more on sub-slab depressurization. These techniques may be superior in some situations and deserve further study.

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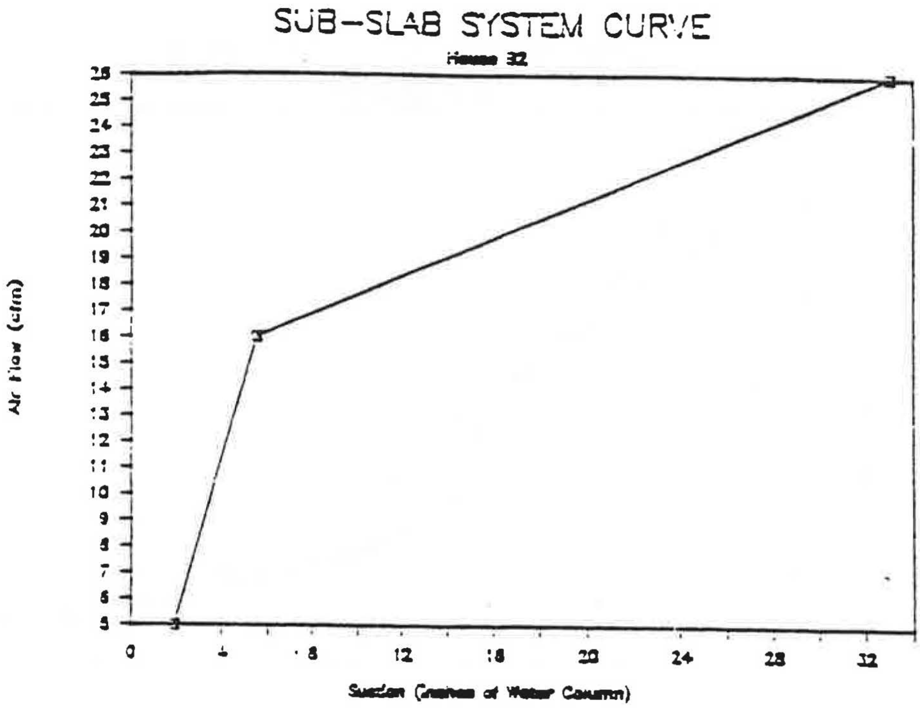

Figure 3. Sub-slab system curve for house B2.

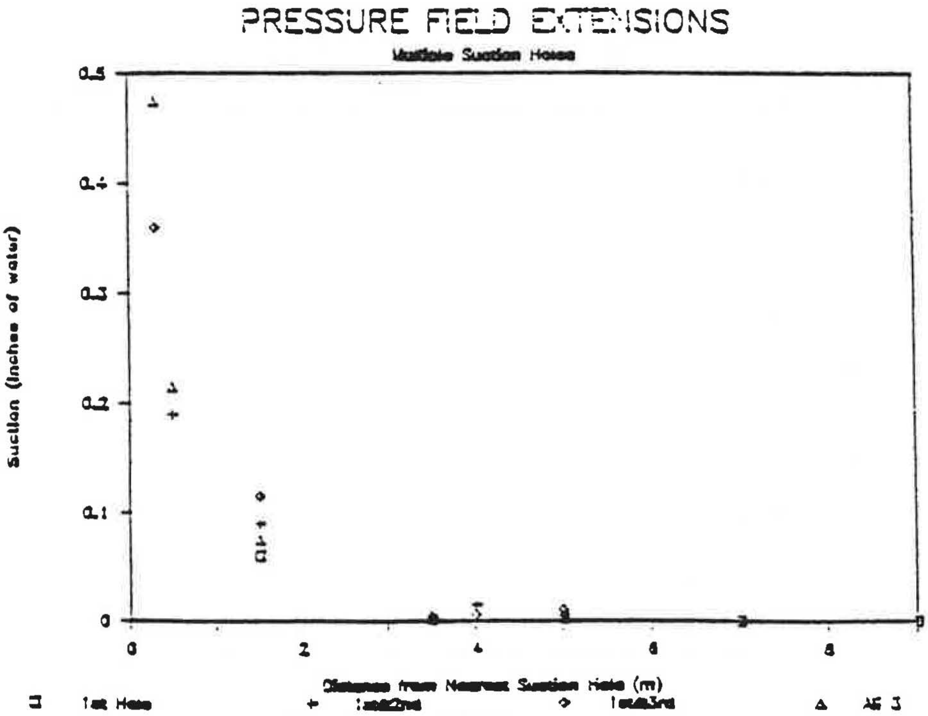

Figure 4. Pressure field extension in house B2 with various combinations of three suction holes.

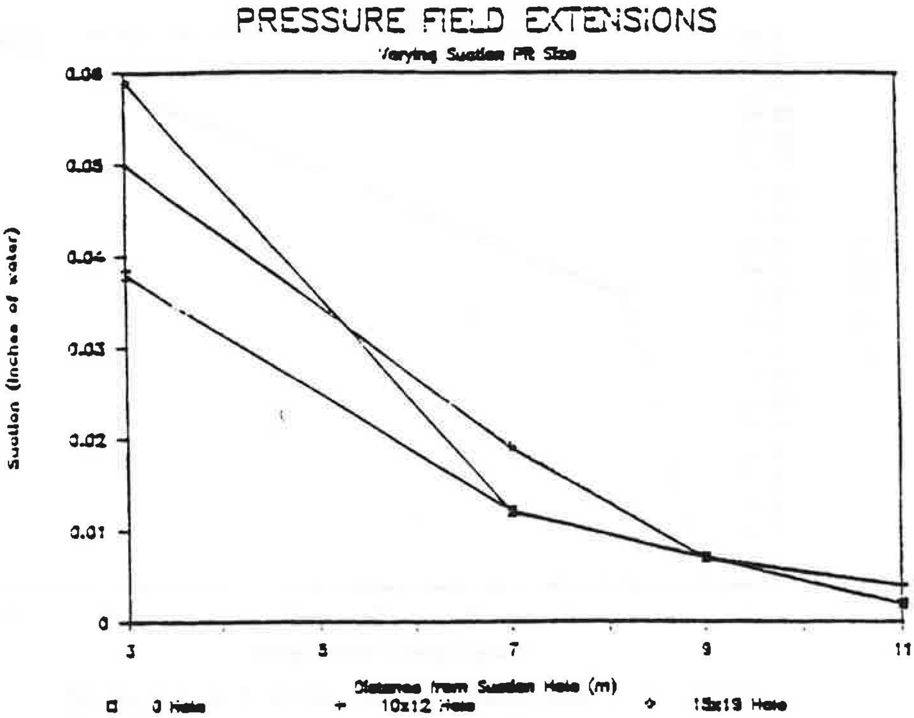

Figure 1. Pressure field extensions for three sizes of suction holes in house B11.

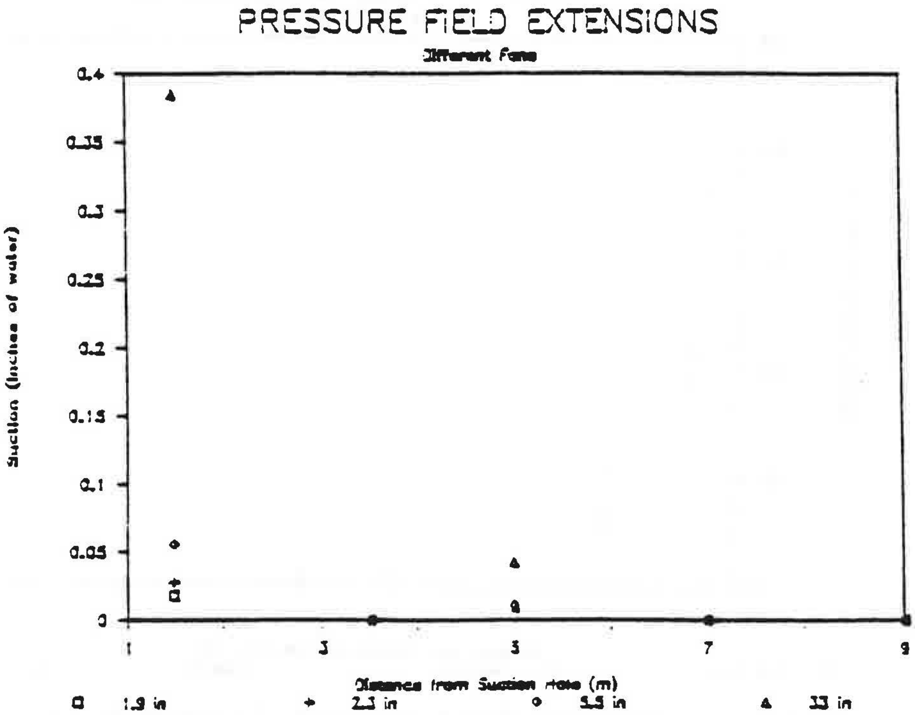

Figure 2. Effects of increased fan suction on the pressure field extensions in house B2.

TABLE 2. RADON CONCENTRATION LEVELS

House ID	Method	Pre-Mitigation pCi/l	Phase I pCi/l	% Reduction	Phase II pCi/l	% Reduction Phase	% Reduction Overall	Phase III pCi/l	% Reduction Phase	% Reduction Overall
B2	CC	61(11/18-11/20)								
		51(1/2-1/4)	27(1/5-1/7)	47						
		52(3/22-3/24)						5.5(4/24-4/26)	41	89
	CRM	29(12/17-1/5)	16(1/5-1/22)	45						
		39(3/11-3/24)			9.3(3/24-4/12)	42	76	4.6(4/12-4/28)	51	88
	ATD	26(12/18-1/4)	15(1/5-2/18)	42						
B11	CC	40(11/18-11/20)								
		42(1/2-1/4)	15(1/5-1/7)	64	3.0(2/19-2/21)	80	93			
	CRM	30(12/17-1/4)	13(1/5-1/22)	57						
			10(2/6-2/16)		3.2(2/17-3/2)	67	89			
	ATD	32(12/19-1/4)	9.2(1/5-2/18)	71	4,2(2/18-8/19)	54	87			
A3	CC	83(11/17-11/19)								
		37(2/13-2/15)	36(2/16-2/18)	3						
	CRM	33(2/2-2/15)	29(2/16-3/3)	12	22(4/13-4/28)	24	33	9.1(4/19-4/21)	59	72
	ATD	23(12/20-2/15)								
B8	CC	36(11/18-11/20)			4.7(7/21-7/24)	57	87			
	CRM	37(2/2-2/12)	11(2/12-3/3)	70	5.0(5/27-6/10)	55	86			
	ATD	22(12/20-2/17)								
A7	CC	65(11/17-11/19)								
		59(3/22-3/24)			4.1(4/26-4/28)	68	93			
	CRM	68(3/10-3/24)	13(3/29-4/12)	81	4.6(4/17-4/28)	65	93			
	ATD	40(12/20-3/24)								
B3	CC	19(11/17-11/19)	4.9(3/20-3/22)	74	5.7(3/29-3/31)	-16	70			
	CRM		7.3(3/8-3/21)	62	3.9(3/31-4/11)	47	79			
	ATD		5.0(12/20-3/22)	74	6.4(4/15-7/14)	-28	66			
A1	CC	12(11/18-11/20)								
	CRM	7.6(4/29-5/24)								
	ATD									
A4	CC	8.7(11/17-11/19)								
	CRM	3.1(5/3-5/24)								
	ATD									

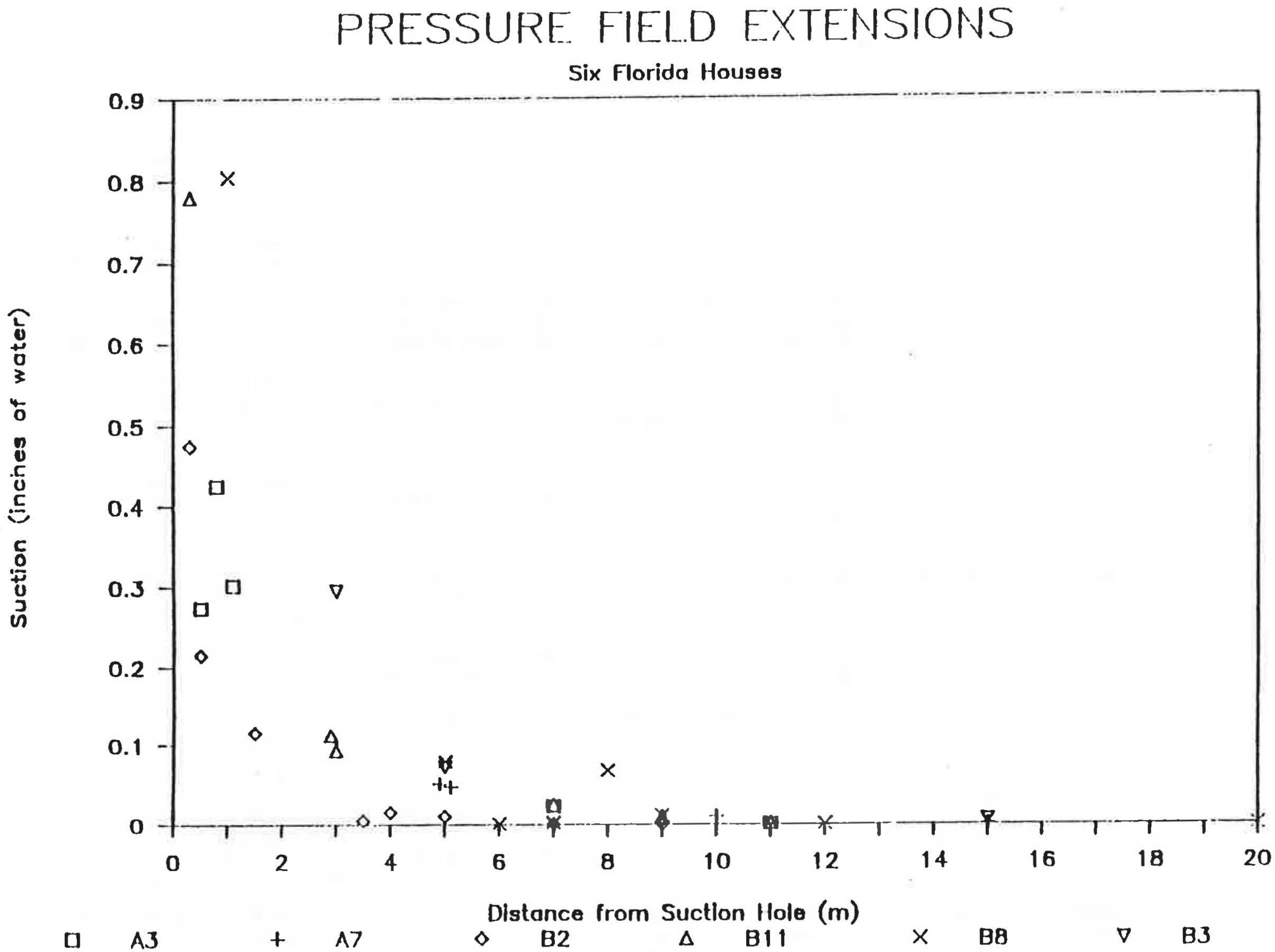

Figure 5. Composite plot of the optimum pressure fields obtained in all six houses using similar fans.